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VAN H. MANNING, DIRECTOR

THE DECLINE AND ULTIMATE PRODUCTION OF OIL WELLS, WITH NOTES ON THE VALUATION OF OIL PROPERTIES

BY

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PREFACE.

One of the problems that confronts petroleum producers and petroleum engineers is the estimation of the total amount of crude oil that may be obtained from oil lands. A producer with some means of determining, even approximately, the total amount of oil that a given area of ground will produce in the future, is able to estimate, within certain limits, the future gross receipts from his property—a bit of extremely valuable information. The engineer or geologist engaged in determining the value of an oil property must know first approximately the amount of oil that can be expected from the area, and, second, the probable yearly rate at which it will be obtained under a specified program of drilling. Furthermore, the determination of taxable income involves an estimate of the total recoverable oil from the lands belonging to oil companies with income enough to place them in the taxable class, for the redemption of invested capital, by allowing yearly deductions from gross income, and is accomplished by deducting each year from gross income the same proportion of invested capital as the yearly oil production bears to the amount ultimately recoverable. Only by estimating the ultimate amount of oil recoverable can invested capital be written off at the proper rate, and that depends on the rate at which the total oil resource is depleted.

In this bulletin Mr. Beal furnishes several new methods for estimating the future output of oil lands and gives curves and other data that should assist oil producers and engineers in determining the probable amount of oil that oil properties in the different fields of the United States will yield. The material is, therefore, presented in two parts. The first part explains in considerable detail the methods that should be used in estimating the future production of oil and the manner of applying those methods to the valuation of oil lands; whereas the second gives in detail such information as was available on the ultimate oil recovered in different fields and the usual rate at which the average oil well in each field will produce.

VAN H. MANNING,
Director.

THE DECLINE AND ULTIMATE PRODUCTION OF OIL WELLS, WITH NOTES ON THE VALUATION OF OIL PROPERTIES.

By Carl H. Beal.

GENERAL STATEMENT.

INCREASING PRODUCTION OF OIL IN THE UNITED STATES.

The oil industry in the United States is further advanced than in any other country, because of American initiative and the development of industries dependent in some way on petroleum or its products. For this reason the output has constantly increased (fig. 1), and as a result this country has produced more than half of the total output of the world. The total past output of the world is approximately 7,000,000,000 barrels of 42 gallons each; of this the United States produced about 4,000,000,000 barrels, or about 57 per cent. The limit of production in this country is being approached, however, and although new fields undoubtedly await discovery, the yearly output must inevitably decline, because the maintenance of a given output each year necessitates the drilling of an increasing number of wells. Such an increase becomes impossible after a certain point is reached, not only because of a lack of acreage to be drilled, but because of the great number of wells that will ultimately have to be drilled. According to figure 1, the daily production per well each year has increased during the last few years. However, this increase is abnormal, being caused by the new pools brought in. Although such a condition may continue for several years, the average production per well will finally begin to decrease on account of the lack of new pools to make up for the normal decline in production of the old ones.

WORK OF THE BUREAU OF MINES.

At present the country is facing a serious shortage of petroleum. By way of preparing for the best way to meet this emergency, the Bureau of Mines has been carrying on technical investigations in

the petroleum industry for several years. The results of these investigations have been published in technical papers and bulletins that have discussed many such topics as methods of drilling, more efficient recovery of oil, exclusion of water from oil wells, storage and protection of oil in reservoirs, manufacture of gasoline from natural gas, and utilization of petroleum fuels. In addition, these publications have covered many chemical problems. Little information has been published, however, and very few investigations have been

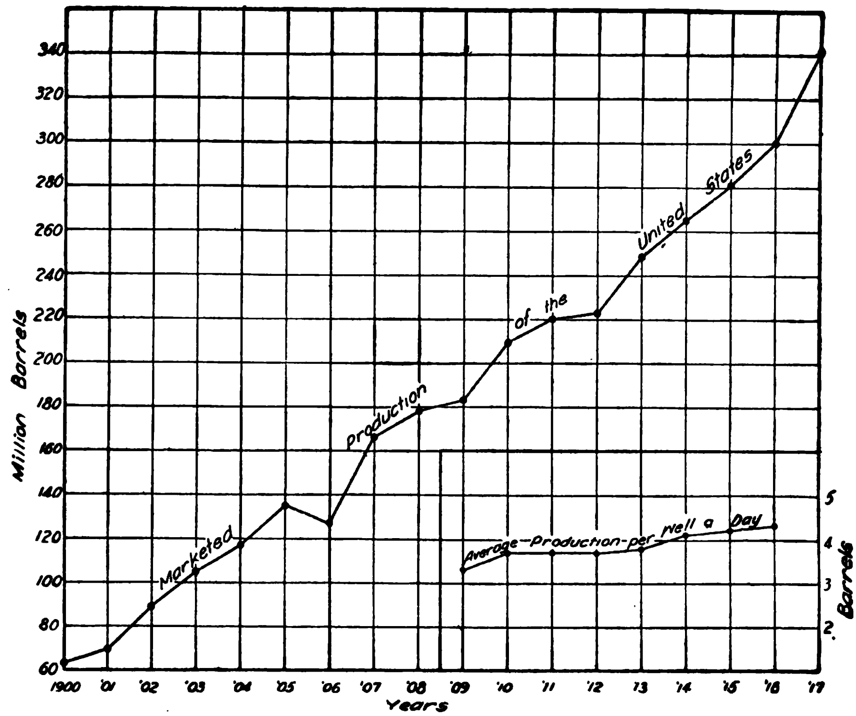

FIGURE 1.—Chart showing annual oil production of the United States since 1900 and the average daily production per well for each year since 1909 of the oil fields of the United States. (Statistics from the United States Geological Survey.)

made dealing with the ultimate amount of oil that a well or a property can be expected to produce under certain conditions or the rate at which the oil can be obtained.

INFORMATION NEEDED BY PRODUCERS.

Formerly the producer did not deem such information essential to the operation of his oil lands with most success, for until the last few years he has not found it necessary to work on as narrow a margin of profit as is common in other kinds of business. Undrilled prospective acreage has been plentiful, so the producer directed his attention

mainly, and with considerable success, to the development of new pools. During the last few years, however, the oil industry has been forced to adopt a more conservative basis. Favorable territory has become scarcer, competition has increased, and the demand for petroleum and its products has created a market that can not be adequately supplied. As a result, small holdings have been consolidated; men of broader vision and greater ability have directed the proper investment of capital; advantage has been taken more generally of technical knowledge that tends to reduce the risk involved in the search for oil, such as the application of geological principles; and business methods have been applied to the industry as its proper development has demanded.

These changes have resulted in the introduction of conservative methods and a growing demand during the last few years for more complete knowledge on the probable future production of oil wells and of oil lands. How much oil will they produce in the future? At what rate will the oil be obtained? These questions occur to oil operators rather often nowadays. If such queries could be answered with even approximate exactness, the producer would be able to obtain a fairly trustworthy idea of his future yearly income and the worth of his property, as well as that of other oil lands he may contemplate purchasing.

Such information is valuable not only to oil operators, but also to engineers engaged in the valuation of oil lands. Unfortunately, those technical men engaged in valuing oil property have access to data, needed in their work, covering small areas only. To determine accurately the weight to be given certain factors controlling the production of oil, the valuer should possess not only a broad knowledge of oil-field conditions, but should also have access to much statistical information that heretofore has been inaccessible to him because of its being in the hands of competing companies. Undoubtedly such information can best be collected, analyzed, and published through the medium of the Federal Government.

INFORMATION NEEDED BY PETROLEUM ENGINEERS.

The training of a large proportion of petroleum engineers has not provided them with a knowledge of the fundamental principles of valuation. This lack of knowledge is not surprising in view of the newness of such work and the recent requirements of the oil industry; but is none the less to be deplored as valuation obviously should be done by the petroleum engineer, because his familiarity with the origin and accumulation of oil and gas and their relation to geologic structure is prerequisite for the scientific valuation of producing and prospective oil lands. Probably, as fewer and fewer large

oil fields are discovered, the oil industry will seek the aid of science more and more, and the technical man will find his services needed in every branch of the industry, from the selection of probable new territory and the determination of the value of producing and prospective oil lands to the utilization of the refined products. For these reasons the writer believes that the petroleum engineer should strive to meet the probable requirements of this specialized branch of petroleum technology.

SCOPE OF THE INFORMATION PRESENTED.

The information in the following pages is offered with the knowledge that some of the conclusions are tentative and have not been proved, but such presentation is necessary in supplying data on a subject of which so little is known. Moreover, some of the methods set forth are not proposed for final adoption by other persons interested in the estimation of future production, but are given with a twofold purpose: (1) To supply such information on the estimation of future production as heretofore the engineer or geologist in commercial work could not obtain, and (2) to stimulate discussion and thought on the subject, for it is only by the painstaking accumulation and publication of such data and the discussion of any new methods evolved from new data that there can be permanent advance. The author, therefore, expects criticism of some of the methods described. Mistakes also may be found, for the subject is new and no precedent was available for compilation of the data. However, the author welcomes any discussion or criticism that will result in advancing the practice of oil-land valuation. Some of the material has been repeated for the sake of clarity.

The scientific appraisal of oil lands is practically new work; surprisingly little has been published on it, and on the methods of estimating the future production of oil wells. But the proper valuation of oil lands must be based on trustworthy estimates of future production, and it is with methods of making such estimates and with the practical application of these methods to appraisals, that this paper is chiefly concerned. Therefore many seemingly elementary features are discussed in detail. If the publication of this bulletin results in stimulating others to increased effort or in leading them to amplify the basic principles presented, the author will feel that a start has been made in the proper direction.

PURPOSE OF THE REPORT.

The present investigation was undertaken for the purpose of supplying some of the material so badly needed in the valuation and more efficient operation of oil properties. Because of the lack of

time for further studies, the amount of data already accumulated and the policy of the Bureau of Mines of publishing as soon as possible any information that may be of use to an industry, the bulletin is issued now. As all the fields of the United States have not been studied in detail, it has been deemed wise to publish the information gathered and later to collect and publish more detailed information on the fields not yet studied.

As already stated, the information given in this bulletin has been roughly divided into two parts, as follows:

Part 1. Methods for estimating the future and ultimate production of oil properties and the application of these methods to oil land valuation.

Part 2. The decline and ultimate production of different oil fields in the United States, including curves showing the actual rate of decline and the ultimate production of various properties and fields; discussions of the conditions existing in the fields represented; and the influence of these different conditions on the rate of production and the amount obtained.

Curves in considerable number are presented; some of them are based on scanty data. It was thought advisable to publish practically all the available information that would be of use because of its being valuable even though incomplete. Many statistics on ultimate and total past production per acre appear in part 2 of the text. Some of these statistics will be of little use to many readers, but of great use to a few. Moreover, the publishing of such detailed information will give other investigators the benefit of practically everything that has been available to the author, and may thus aid them in the solution of other and more complex problems.

COLLECTION AND COMPILATION OF THE DATA.

The collection of data was begun in the Oklahoma fields during the first part of 1916 while the writer was Federal oil and gas inspector for the Five Civilized Tribes. The other chief fields of the country were visited and information regarding production was collected during the next 18 months. The report was put in final form for publication during the spring and summer of 1918.

The information given represents the results of more than a year's work in compiling figures transferred from the books of various oil companies and in making the thousands of calculations necessary for preparing the charts and statistics that cover the annual yield of about 20,000 wells representing, as a rule, the most typical examples of production decline.

More information was available in some fields than in others; furthermore, the need for detailed study was more pressing in some

fields. The Oklahoma fields were studied in greater detail than any of the others, information of varying fullness having been obtained from the Nowata-Chelsea district in northern Oklahoma, the Bartlesville field, the Osage Indian Reservation, the Glenn pool, the Cushing pool, the Ponca City pool, and the Healdton field.

Several production records of properties in the shallow oil fields of southeastern Kansas were available for study. The Augusta and El Dorado fields, in Butler and Montgomery Counties, at present furnish the bulk of the Kansas production, but it was not possible to obtain any records of production long enough to be of much use in the present work.

The fields in northern Texas and Louisiana and the salt-dome fields of the Gulf coast were studied in some detail. Present knowledge of the underground geology of the Illinois field makes possible the obtaining of data that will probably be of much use to operators and technical men in that State.

Little information was collected regarding the Lima-Indiana field in northwestern Ohio and Indiana and the Appalachian field, which extends over parts of New York, Pennsylvania, West Virginia, Ohio, and Kentucky. The productive areas of the Appalachian fields are of such extent, the oil and gas occur under such a wide range of conditions, and the production is from so many different sands that it was not deemed advisable to spend as much time in this field as in some of the younger fields. The data can be collected in more detail later and be presented in other publications.

The California fields were not studied in the detail they deserved, because of the variable conditions under which oil is produced and also because of a lack of time enough for collecting and compiling the wealth of information available in that State. Already some work of this kind has been done in California. In 1915 the appraisal committee of the Independent Oil Producers' Agency compiled composite decline curves for several of the most important California fields. These curves were published by Requa[a] and some of them are reproduced in this bulletin for the purpose of comparison with similar curves constructed by the author.

In collecting the material, statistics on production were usually deemed of first importance. Other information, such as the relative location of the productive oil wells, their depth, the thickness of the productive sand, the initial production, the viscosity of the oil, and the closed pressures of the oil wells, was included when available. It was rarely possible to obtain production records of individual wells except in California. In most of the other fields the records

[a] Requa, M. L., Methods of valuing oil lands: Am. Inst. Min. Eng., Bull. 134, February, 1918, pp. 409–428.

of production are and have been kept only by properties; that is, the production of all the wells on each property was combined.

ACKNOWLEDGMENTS.

The author gratefully acknowledges his indebtedness to W. A. Williams, former chief of the petroleum division of the Bureau of Mines, under whose direction the work resulting in the publication of this bulletin was done; to Chester Naramore, successor to Mr. Williams as chief of the petroleum division, who has offered many valuable suggestions; and to A. W. Ambrose, of the bureau, for suggestions and assistance in compiling the material in the office. He also acknowledges the aid rendered by several of the different State geologists in the United States, as well as by Dr. Inouyi, Director of the Japanese Geological Survey, who kindly furnished data on the Japanese oil fields. J. O. Lewis, who has done considerable work on the same subject, has courteously made many suggestions; in fact many of the ideas presented are the direct outgrowth of suggestions he has made. The manuscript was carefully read and numerous valuable suggestions were made by Roy E. Collom, Clarence G. Smith, E. D. Nolan, J. O. Lewis, R. B. Moran, and R. V. Mills. Acknowledgments are also due to scores of oil companies who have furnished information and allowed the author access to valuable production data, without which this could not have been prepared. The author desires to express his indebtedness especially to the various officials of these companies: In California, the Southern Pacific Co., the Standard Oil Co., the General Petroleum Corporation, the Santa Fe, and the Shell Co. of California; in Wyoming, the Midwest Oil Co.; in Oklahoma and Kansas, the Prairie Oil & Gas Co. and the Gypsy Oil Co.; in Texas, the Producers' Oil Co. and the Gulf Production Co.; in the eastern fields, the Chartiers Oil Co., the Ohio Oil Co., the National Transit Co., the Pure Oil Co., the Ohio Fuel Supply Co., the Ohio Cities Gas Co., and Brundred Bros., of Oil City, Pa. Many other companies have furnished valuable information. A. R. Elliott and J. G. Shumate, of the Bureau of Mines, drew the charts and figures.

DEFINITIONS.

In this bulletin several new terms have been used; these as well as some old terms that may be used in more than one sense are defined below:

Total production is the total amount of oil produced in the past by a well, property, or field.

Future production is the amount of oil that will be produced in the future by a well, property, or field.

Ultimate production (or the recoverable oil) is the amount of oil that a well, property, or field will ultimately produce. The ultimate production is therefore the sum of the past, or total production, and the future production.

The decline of a well is the decline or falling off in the production of a well.

The decline of a property means the falling off or reduction in yield based upon the average amount of oil each well makes. The actual daily production of the property may be increasing while the actual daily production per well may be decreasing. This decrease is the decline of a property.

A per cent decline curve is one showing the decline in the production of a well, property, or field, each year's production being expressed as percentages of the first year's production, which is taken as 100 per cent. For example, a well may produce 10,000 barrels the first year, 5,000 barrels the second year, and 3,000 barrels the third year. The percentages of this property for the first, second, and third years are successively 100, 50, and 30 per cent.

The cumulative percentage of a property is the sum of the percentages for all years. In the preceding example the cumulative percentage is 180.

The ultimate cumulative percentage is the sum of the past and the estimated future percentages; it is expressed as a percentage of the first year's production and may be further defined as the cumulative percentage of the property at the time of its exhaustion.

The expectation of a property or well may be defined as the amount of oil that is expected from a property or well—the future production.

Total production per acre is the average amount of oil produced in the past from each acre of a drilled tract of land.

Ultimate production per acre is the average amount of oil produced ultimately from each acre of a drilled tract of land.

Production per acre-foot is the total or ultimate production per acre divided by the average thickness of the productive sand.

Initial production is used in this bulletin in two different senses: (1) The production of a new well for the first 24 hours; and (2) the average daily production of a new well during the first year. Where the term is used in the latter sense attention is called to the fact.

Decline of initial yearly production is the decline in the daily production for the first year of wells drilled on a property for several consecutive years. For instance, if the average daily production of new wells drilled on a property for the years 1907, 1908, and 1909 were successively 50, 30, and 20 barrels, these figures are the decline, or decrease, of initial yearly production.

A composite decline curve is a curve showing the average per cent decline of many wells or properties.

An appraisal curve is a series of curves used to determine the amount of oil that under certain conditions will be produced in the future by the properties in the area for which the curve has been made.

Oil content is the amount of oil contained in a given porous reservoir or oil sand.

Recoverable oil is the amount of oil that ultimately may be recovered with profit from such a porous reservoir. It is necessarily a relative term, as the amount of oil taken from a field (the recoverable oil) varies with the price of oil, and with several other factors. More oil will be recovered when the price is high than when it is low. A distinction should be drawn between oil naturally recoverable and the extra amount possibly recoverable by suction, compressed air, and other stimulative processes.

Interference between wells signifies the interfering drainage areas of adjacent wells. In general, as a well becomes older its drainage area extends—the oil coming from greater distances—and often reaches and interferes with the drainage area of another near-by well.

PART 1.—METHODS FOR ESTIMATING THE FUTURE AND ULTIMATE PRODUCTION OF OIL PROPERTIES AND THE APPLICATION OF THESE METHODS TO OIL-LAND VALUATION.

GENERAL STATEMENT.

Many workers in the petroleum industry do not realize that the most valuable and useful knowledge an oil operator can possess with reference to his property is (1) the ultimate amount of oil the property will probably produce, and (2) the rate at which the oil will be obtained under a specified drilling program. Generally, the pumping costs may be closely computed and the operator may be able to tell within narrow limits the outlay of capital required to drill a well to a given depth. Such data are, of course, invaluable, but if he knew, even within rather wide limits, the probable amount of oil he would be able to sell from his lease each year, the advantages would be manifold. He would be able to determine with fair accuracy the sale value of his property or the amount he could afford to pay for another, to calculate the proper rate of capital redemption, to estimate the proper rate of drilling to insure the greatest return in income, and to compute his probable future annual income.

Oil properties, however, differ so much in character, and the conditions affecting the recovery of oil vary so greatly, that it is impossible to lay down an absolute rule that can be applied with certainty to estimating the future production of all properties alike. However, by studying the conditions under which oil is being and has been produced and the factors that have governed the amounts properties have produced under certain conditions, as well as the rate at which oil has been obtained under those conditions, the estimation of future output is by no means so hopeless as at first it may seem. In fact, if data enough are collected, close estimates of the future production of oil properties can ordinarily be made.

PREVIOUS LITERATURE.

Publications dealing with estimating future production or with valuing oil land are few, because practically no intensive studies have been made. Such textbooks as those by Johnson and Huntley,[a]

[a] Johnson, R. H., and Huntley, L. G., Principles of oil and gas production, 1916. 371 pp.

Thompson,[a] and Bacon and Hamor[b] contain some valuable information on methods of estimating future output, and Arnold[c] gives a theoretical curve of final decrease. Washburne[d] gave a method of determining oil content by what is known as the "saturation method."

More recent publications are by Pack,[e] who gives an excellent résumé of previous methods, and by Lewis and the present author,[f] who present some new methods for making estimates.

One of the earlier papers on the valuation of oil lands was presented in 1915 by Lombardi.[g]

Hager[h] offers examples of the method of determining the amount that an operator could afford to pay for a property under certain assumed conditions. Requa,[i] in 1912, gave some information on this subject, and a more recent paper[j] by the same author presents the method adopted by the appraisal committee of the Independent Oil Producers' Agency of California for determining the future production and value of several properties in that State.

A bibliography containing the titles of several other papers dealing directly or indirectly with these subjects is given at the end of this bulletin.

REVIEW OF PREVIOUS METHODS.

Three general methods are commonly employed for the estimation of future output. These are (1) the saturation method, based on a calculation of the oil content of the productive sand, (2) the production-curve method, which consists of determining from the decline in production of a well in the past the amount of oil that probably will be produced in the future, and (3) the production per acre method, which estimates the future output by comparing actual recoveries per acre from similar properties in the same district or in one where the conditions are comparable.

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[a] Thompson, A. B., Petroleum mining and oil-field development, 1910. 362 pp.

[b] Bacon, R. F., and Hamor, W. A., The American petroleum industry, 1916. 963 pp.

[c] Arnold, Ralph, The petroleum resources of the United States: Econ. Geol., December, 1915, pp. 695–712.

[d] Washburne, C. W., The estimation of oil reserves: Am. Inst. Min. Eng., Bull. 98, February, 1915, pp. 469–471.

[e] Pack, R. W., The estimation of petroleum reserves: Am. Inst. Min. Eng., Bull. 128, August, 1917, pp. 1121–1134.

[f] Lewis, J. O., and Beal, C. H., Some new methods for estimating the future production of oil wells: Am Inst. Min. Eng., Bull. 134, February, 1918, pp. 477–504.

[g] Lombardi, M. E., The valuation of oil lands and properties: International Eng. Cong., San Francisco, September, 1915. The same paper with a few changes was published in Western Eng., vol. 6, October, 1915, pp. 153–159.

[h] Hager, Dorsey, Valuation of oil properties: Eng. and Min. Jour., vol. 101, May 27, 1916, pp. 930–932.

[i] Requa, M. L., Present conditions in the California oil fields: Am. Inst. Min. Eng., Bull. 64, April, 1912, pp. 377–386.

[j] Requa, M. L., Method of valuing oil lands: Am. Inst. Min. Eng., Bull. 134, February, 1918, pp. 409–428.

SATURATION METHOD.

BASIS OF METHOD.

The saturation method is based on several factors the values of which are uncertain, these factors being the porosity, the thickness, the extent, and the saturation of the oil sand. From these the percentage of oil that may be recovered is estimated. The capacity of an oil sand of uniform thickness and porosity can be determined with fair accuracy from samples of the sand from different wells, especially if the wells are scattered over the area and several determinations are made from a number of representative samples. The most difficult determination in this method is the proportion of the total oil content that may be recovered from the sand. This is closely related to the error resulting from estimating the saturation of the oil sand.

OIL CONTENT OF SAND AND OIL RECOVERED.

Usually more oil is left underground than is brought to the surface; in fact, only a small percentage of the total oil content of a sand is ordinarily recovered. The so-called recovery factor varies widely according to the conditions controlling the production of oil and gas. Hence an arbitrary value nearly always has to be assigned to the recovery factor. As the accuracy of the whole procedure is thereby greatly reduced, the estimate becomes little more than a guess.

The difference between oil content and the amount of oil that may be recovered (the ultimate production) must be kept carefully in mind. The factors that govern the amount of oil present in a sand of course control the amount of oil that can be recovered from it. But other factors must be studied. The recoverable oil, or the ultimate production of a sand underlying an area, is the quantity that may actually be taken from the sand rather than the amount present in it. This recoverable oil is a percentage of the total oil content and varies with the conditions of occurrence of the oil and the conditions of production. Unquestionably a much larger percentage of the oil content can be recovered from a coarse porous sandstone subjected to a high gas pressure than from a fine-grained denser sandstone under no great pressure. The coarse porous sand offers little resistance to the flow of the oil toward the well, whereas, with a fine sand and a low gas pressure, the production is retarded, both by the greater frictional resistance and the lack of expulsive force. Undoubtedly the recovery factor varies with the conditions between these two extremes.

VARIABILITY OF RECOVERY FACTOR.

It should be borne in mind that the recovery factor is not the same for all pools nor even the same for all properties in a pool. The factor may differ for different parts of a single property, as it depends on the conditions that influence production and may be as variable as they. For instance, the recovery factor of a small area on the crest of a dome may be much greater than that of another

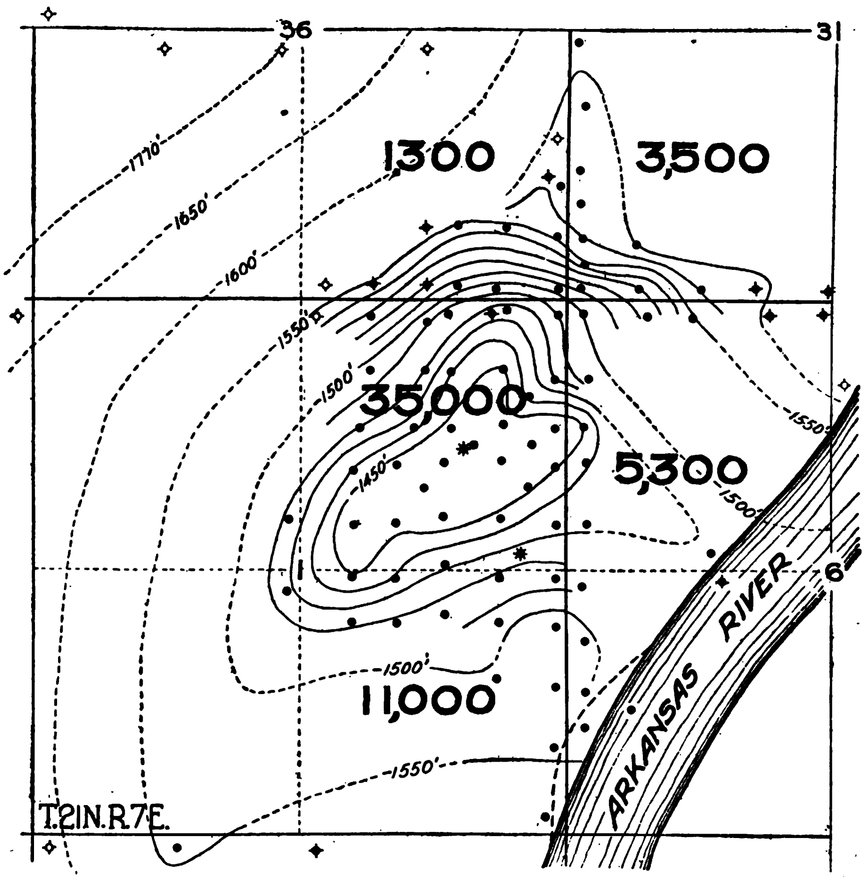

FIGURE 2.—Sketch showing the relation between total production per acre (in barrels) and geologic structure in the Boston pool, Okla.

area a few hundred feet nearer the edge of the pool. As much oil is contained in the sand in one place as in the other, but the conditions governing its expulsion are less favorable in the second tract than in the first, because of the smaller proportion of dissolved or compressed gas. Figure 2 shows this relation excellently; just as much oil was originally contained in the sand on the edge of the pool, but the ultimate production of those areas is much smaller. In

the figure the dots are oil wells; the dots with four points are dry holes; the circles with four points are abandoned wells; the stars are gas wells.

ESTIMATION OF RECOVERY FACTOR.

The recovery factor may be estimated in several different ways. One method is by computing the oil content of the productive sand from the thickness and porosity. By estimating the ultimate production that will probably be obtained from this district, the recovery factor, or percentage recovery, may be obtained by dividing one by the other. In using this method, however, it is necessary to assume that the entire productive stratum and all the pore space, or some definite part of it, is saturated with petroleum or compressed gas; estimates of the recovery factor made in this way have been based on the assumption that a small part of the sand was saturated when in reality the saturation was greater, so that the recovery factor was smaller than estimated. For example, if the pore space of a sand were estimated to contain 10,000 barrels of oil per acre and the recovery factor were desired, the actual production per acre (here assumed as 2,000 barrels) divided by the estimated oil content of 10,000 barrels would give a recovery factor of 20 per cent. This factor might be assumed to be much too low, and the conclusion might be reached that the whole sand was not saturated, leading to the substitution of a saturation factor of 50 per cent, which would decrease the oil content to 5,000 barrels per acre and thereby raise the recovery factor to 40 per cent. As a matter of fact, the recovery was probably 20 per cent instead of 40 per cent, and the sand was completely saturated. It is believed that a similar error has often been made in using a saturation factor to determine oil content or a recovery factor, and that in reality the recovery factor was smaller than estimated. The author can not conceive a uniformly porous sand partly saturated with oil and gas under pressure. If the sand be only partly saturated, the saturated portion must be separated from the other by impervious barriers.

If the variables mentioned above could be satisfactorily and easily determined, this method of estimating the recovery factor would be easy to use and therefore of great value, as a single well on a property would make available some of the information on which future production could be based.

Lewis[a] gives other methods of estimating the recovery factor, as well as estimates made by various persons of the amount of oil left underground, these estimates ranging from 25 to 90 per cent; he also presents statistics that lead him to believe that only 10 to 20 per cent of the oil is ordinarily recovered. This is much lower than the usual estimate of approximately 50 per cent.

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[a] Lewis, J. O., Oil-recovery methods: Bull. 148, Bureau of Mines, 1917, pp. 25–32.

DISADVANTAGES OF SATURATION METHOD.

The disadvantages of the method may be summed up as follows: (1) Impossibility of obtaining information as to the exact thickness of the "pay"; (2) difficulty of accurately determining the voidage, because of differences in porosity; (3) practical impossibility of determining the percentage of oil recovered from the sand, as the proportion varies with temperature, pressure, character of the oil, character of the sand, relation of edge-water to oil, encroachment of water, the space in the reservoir occupied by gas, and the underground migration of oil.

The author believes that the value of the saturation method has been overestimated, and is not willing to concede that it can be applied under ordinary circumstances without the making of hazardous assumptions. Hence it should be used only until data are available for the use of other methods. Conceivably the method might be used to obtain an approximate idea of the probable productivity of a newly discovered reservoir under ideal conditions, such as the accumulation of oil being controlled by a definite anticline or dome and the sand being probably of uniform thickness and porosity. However, such a combination of ideal conditions is seldom encountered. Furthermore, the existence of such conditions can not be known until several wells are drilled, and then information enough is available to allow the use of a more trustworthy method.

PRODUCTION-CURVE METHOD.

BASIS OF METHOD.

The production-curve method is based on the recorded production of the wells themselves; in other words, future recovery is based on past yield, and as the record of the actual output of a well is an index to the quantity of recoverable oil rather than to the total oil content, a determination of the recovery factor is unnecessary. In using this method the output of the well is plotted for time periods for the term of production, and to estimate the future output the curve thus determined is projected from the terminus to the point representing the minimum production at which the well can be pumped with profit. This method is most valuable for estimating the future output of individual wells or a group of wells on a property, but often the production records of individual wells are not available and it is necessary to construct a curve showing the decline in production of a property.

In this event it is a better practice to construct the decline curve of each property by computing and plotting the average daily output per well (total property production divided by the number of

wells producing) for each time period. If all the wells were completed at the same time such a curve would show the decline in production of the property as accurately as the decline curve of one well would show its production. But all the wells on a property are rarely drilled at once, and as a result the average daily production per well may increase until the later wells can no longer offset the combined decline of the older wells. This time may be a year or two years after the initial well is drilled, but as a general rule it has been found that curves showing the average decline of wells on different properties in pools like those in the Mid-Continent field are little affected by slow or rapid rates of development (pp. 21–24).

MERITS OF METHOD.

The author believes that the estimating of future output, especially the future output of small areas, by the production-curve method, and by certain variations of it to be given later, is the most practical method. One of the great disadvantages of the method is the impossibility of constructing a decline curve for a property until the property has produced for some time. This defect, however, may be offset, if data enough are at hand, by applying the decline curve of one district or property to the probable production of another similar district or property. It is believed that if data enough are gathered and analyzed, the application of typical production curves of properties or wells producing under certain specified conditions can be applied with considerable certainty to other properties where approximately the same conditions will influence output.

PRODUCTION-PER-ACRE METHOD.

MANNER OF USE.

The production-per-acre method is used considerably with the production-curve method to estimate future and ultimate production. It consists in reducing the actual output of exhausted properties, or of properties so nearly exhausted that their ultimate production can be estimated with fair accuracy, to the amount of oil produced per acre, and in applying the values to other similar properties from which approximately the same ultimate production may reasonably be expected. Estimating ultimate production per acre from the recoveries obtained from similar older properties is possible, of course, only where records of past output are available; yet it is believed that with such information this method should be used much more than it has been, because usually most of the production from an acre of ground is obtained during the first two or three years and the proportion of the total obtained after that

time is small compared with that already recovered. Hence fairly accurate estimates can be made of the ultimate production of an acre of ground after it has produced two or three years, and these data can then be applied to other districts where the conditions affecting output are similar and the properties are operated in a like manner.

FACTORS GOVERNING THE DECLINE OF OIL WELLS.

GENERAL STATEMENT.

Many factors influence the decline of oil wells. The effect of some is great and should be given due consideration; that of others is small and may be neglected. None of the factors will be discussed at length in this report, except the rate of development, which often is overlooked and sometimes is greatly overestimated, especially in the Mid-Continent field.

RATE OF DRILLING.

To determine the influence of the rate of drilling on the decline of a group of wells, several properties in the Glenn pool (Okla.) and in the Blue Creek field (W. Va.) were studied. In this study those properties in the Glenn pool that were more than one-half drilled the first year were separated from those that were less than one-half drilled in that time. The average daily production per well for each year for each property was determined for the two classes. They were averaged together and the decline plotted.

Figure 3 shows these curves. In this figure the solid line is the decline of those properties that were more than one-half drilled the first year; the dashed line is the decline of those properties that were less than one-half drilled the first year or, in other words, those on which the wells were drilled gradually through several years; and the dotted curve represents the composite decline of the properties entirely drilled the first year. The decline of these was considerably slower because of the wells being smaller. The figures along the three curves indicate the number of properties used in constructing the curves.

It will be observed that the decline of the properties developed gradually, was less during the first three years, and greater thereafter than that of the properties that were more than one-half drilled. An analysis of two concrete examples follows.

DECLINE OF SLOWLY DRILLED PROPERTIES.

Select one property, comprising 160 acres, from those that were gradually developed; assume that only 5 equidistant wells were drilled the first year; then approximately 30 acres would contribute to each

well, and for that reason the wells would "hold up" unusually well and show a high average yield for the first year. Next, assume that 5 more wells were drilled the year following; then the area allowed

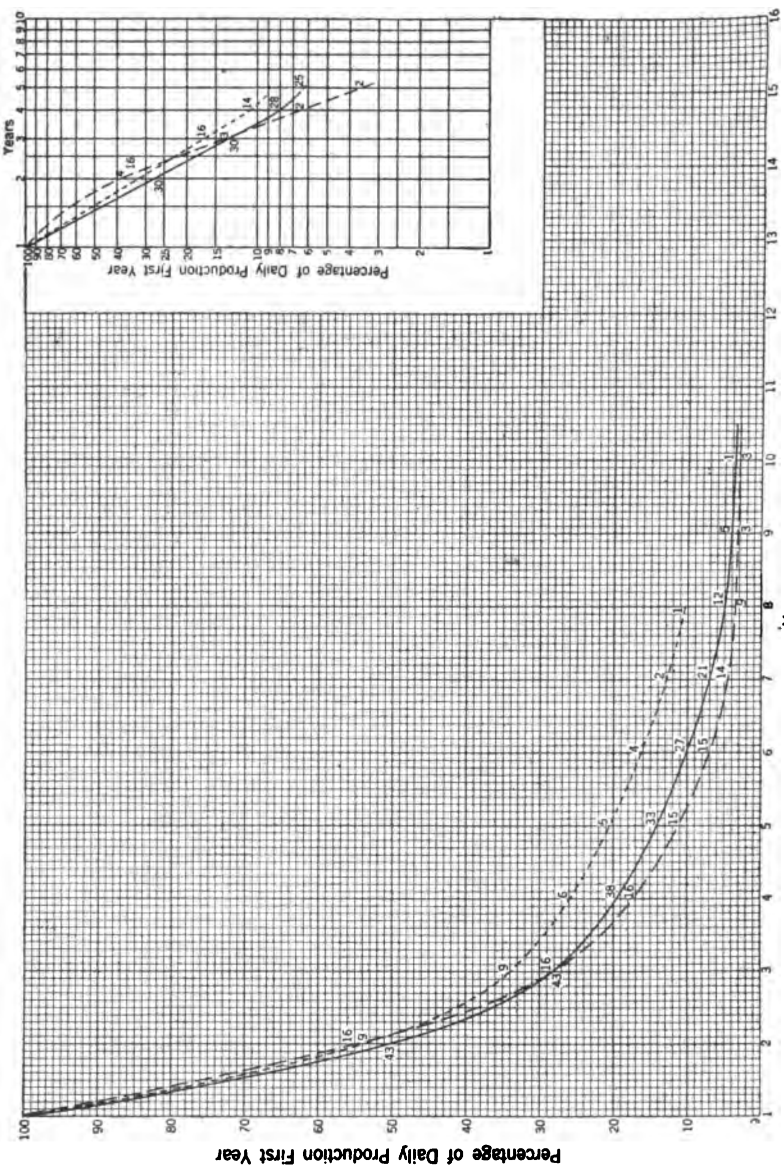

FIGURE 8.—Composite decline curves of different groups of properties in the Glenn pool, Okla., showing the relation between the rate of development and the rate of decline. Inset shows curves for similar groups of properties in the Blue Creek field, W. Va., plotted on logarithmic coordinate paper.

for each well, if all were practically equidistant, would be 16 acres. As this acreage is much more than the average for the Glenn pool, during the second year also the average daily production per well

would be larger than if the wells were more closely spaced. If during the next year 10 more wells were drilled, there would be a total of 20 wells producing on the 160 acres, an average of 8 acres per well. Thus the contributory area would be cut down more, and the new wells being adjacent to wells that have produced one or two years would stand little chance of being in areas unaffected by drainage. These new wells must be considered, however, in computing the average daily production per well for the third year and for succeeding years. If it were possible to obtain the production data for each of the wells it would be seen that the output of the first wells would decline slowly, but as soon as the wells drilled during the third year started producing the output would fall off sharply. The new wells would have a smaller initial production and in addition would probably decline more rapidly than if they had not been drilled into a partly drained sand in which the expulsive force of the gas had become much less. With heavy oil, tight sand, and wider spacing of the wells, the decline of the later wells would probably not be so rapid, but if the communication between all the wells on the property were easy, the interference would extend rapidly.

DECLINE OF RAPIDLY DRILLED PROPERTIES.

Consider a property of 160 acres in that class of properties that have been more than half drilled the first year. Suppose 16 wells were drilled the first year, giving 10 acres per well. Drilling 4 more wells the second year would reduce the area per well to 8 acres. The first 16 wells would show a much smaller average daily production for the first year than the wells drilled the first year in the slowly developed tracts, because of there being only 10 acres contributing to each well instead of about 30 acres, and because of interference starting and cutting down the average production per well. During the second year the effect of the new wells would be proportionately much less. On such a property, as compared with the other, there would be a smaller average production of the wells during the first year, but also a lower rate of decrease during the second year.

The same reasoning applies to the decline of properties completely drilled the first year.

STUDY OF PROPERTIES IN THE BLUE CREEK FIELD (W. VA.).

Fifty properties in the Blue Creek field (W. Va.) were studied in the same manner. The inset on figure 3 shows the curves, plotted on logarithmic coordinate paper, from the records of the three different classes of properties—that is, those fully drilled the first year, those more than one-half drilled the first year, and those one-half or less

than one-half drilled the first year. The relationship of the curves is the same as that of the curves for the Glenn pool (Okla.).

One interesting similarity is that the curves representing the decline of slowly and rapidly drilled properties in both districts cross each other the third year.

METHOD OF SHOWING THE DECLINE OF OIL WELLS.

GENERAL STATEMENT.

The method adopted by the author for showing graphically the rate at which oil is obtained is not new and has been in rather general use among geologists, especially in the California oil fields, for several years. Briefly, the method consists in showing each year's production as a percentage of the first year's production; that is, where the production record of a whole property is involved, the average daily production per well for the property for each year is computed and the first year's average called 100 per cent. Next, the average daily output for each succeeding year is shown as a percentage of the first year's output and these percentages are plotted, the first year being called 100 per cent. For example, if the average daily production per well on a property the first year was 1,000 barrels, the second year 500 barrels, the third year 300 barrels, the decline of the property would be expressed in percentages by plotting the first year as 100 per cent, the second year as 50 per cent, the third year as 30 per cent, and so on to the exhaustion of the property. In the present bulletin the author has endeavored to show the average rate of decline for a whole field by averaging the decline curves of as many representative properties as possible. For some fields several hundred properties, involving probably 4,000 or 5,000 wells, were used to construct these composite decline curves.

EFFECT OF DIFFERENCES IN INITIAL OUTPUT.

One objection to the use of composite curves is that the decline curves of wells of different initial yearly production are employed in determining the average. In general, wells of small initial yearly production decline more slowly than those of large; hence, if the composite decline curve is used in estimating the future production of a well of larger output than the average the estimate will considerably exceed the actual production, and the estimates of the future production of small wells will be unduly low.

Composite or average curves, regardless of this fault, have much value, however, and can be used to good advantage if due allowances are made for the possibilities of error. Often, because of lack of in-

formation, it is impossible to make such allowances, and it is then necessary to use the curves as being the best available basis of estimate.

DIFFERENCES IN DECLINE OF PROPERTIES IN BARTLESVILLE FIELD (OKLA.).

To show further the fundamental error in promiscuously using such curves without making allowances for differences in the rate of decline of large and small wells, figure 4 has been prepared. It shows the rates of decline of properties in the Bartlesville pool (Okla.), on which the average daily production per well the first year was different. In constructing these curves, all properties were separated into six classes according to the average daily output per well during the first year. These six classes were those in which the wells averaged the first year zero to 10 barrels, 11 to 20 barrels, 21 to 30 barrels, 31 to 40 barrels, 41 to 50 barrels, and in excess of 50 barrels a day. The first year's daily production for each property was called 100 per cent, and the production for succeeding years for each property was shown as a percentage of the first year's production. The average yearly percentages for each class thus obtained were plotted on logarithmic coordinate paper, because with this kind of paper the curves came out more nearly as straight lines.

The difference in decline for the different classes of wells is striking. For example, the wells which made less than 10 barrels daily the first year average during the second year 61 per cent of that; whereas wells that made more than 50 barrels a day the first year average during the second year about 29.5 per cent as much. The rate of decline of wells averaging between 10 and 50 barrels a day the first year varied regularly between these two extremes.

The dashed line shows the composite curve for all wells and clearly exemplifies the error of using the average curve for the whole field in estimating the future production of wells making less than 10 and more than 50 barrels a day. Had the average curve been projected at the end of the second year, as shown by the dotted line, it would have come close to giving an accurate prognostication of the future decline of the average well in that pool.

APPLICATION OF LAW OF AVERAGES.

Average, or composite, curves are based on the law of averages. There are, of course, many properties that will not follow any of the decline curves shown in figure 4. Some properties produce less than they should because of natural and artificial causes that affect the yield. In fact, there are several factors that can cause the decline

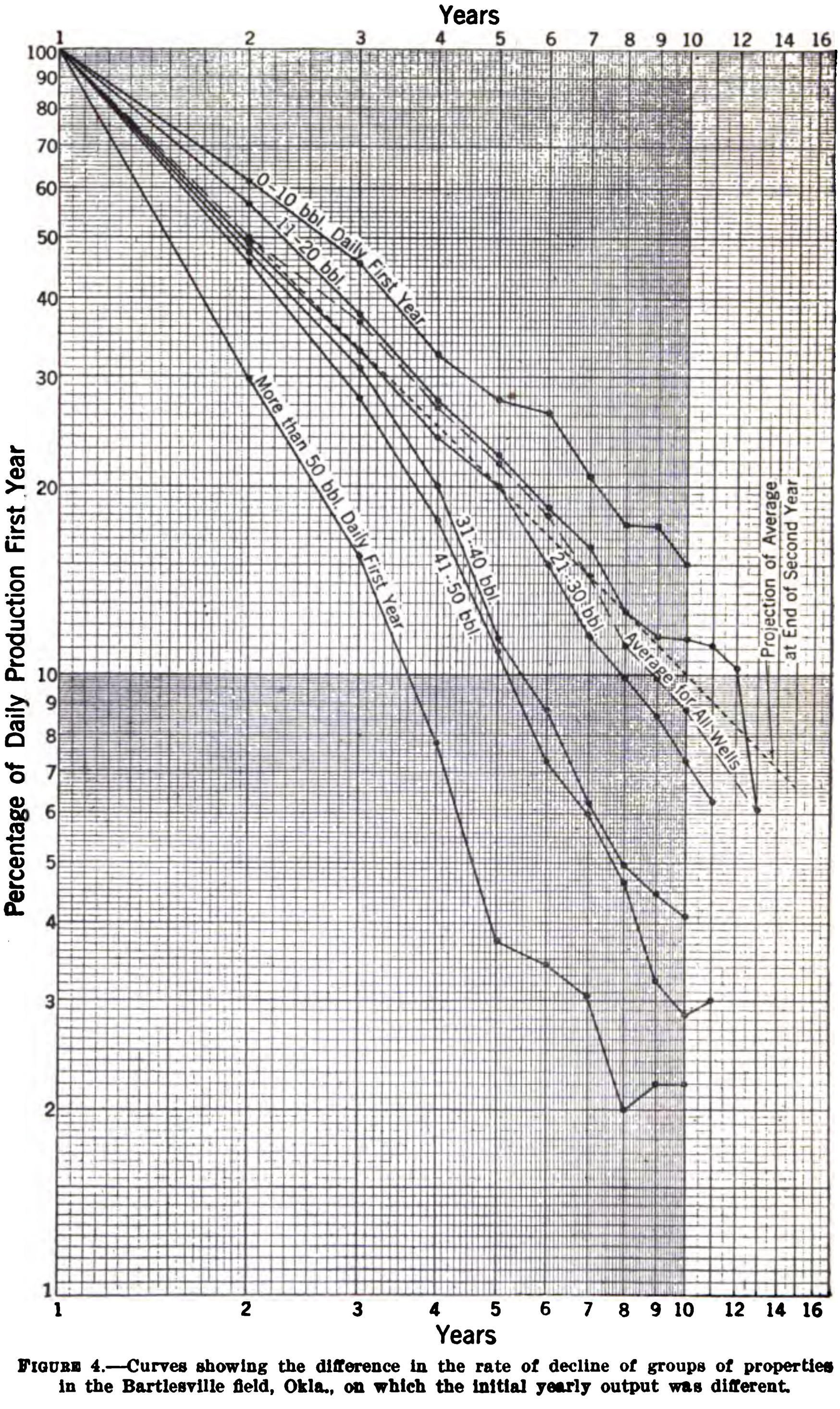

FIGURE 4.—Curves showing the difference in the rate of decline of groups of properties in the Bartlesville field, Okla., on which the initial yearly output was different.

curves of different properties to become irregular, but the chances are that the decline of a property will follow some one of the curves shown in figure 4.

As an example of the method by which averages are applied, the familiar instance of the probabilities of the stature of man may be cited. If 1,000 men are selected at random, fully 500 of them will be between 5 feet 5½ inches and 5 feet 9½ inches high, or their average height will be 5 feet 7½ inches. Of the same 1,000 men probably 10 would be shorter than 5 feet, and three or four would be taller than 6 feet. But the chances are greater of selecting at random from the 1,000 men a man approximately 5 feet 7½ inches tall than of selecting a man of any other height. The chances are slight that one would obtain in this random choice a man less than 5 feet tall, and still less that one would select a man more than 6 feet tall.

The same principle applies to the average decline of oil properties. The chances are that a property selected at random in the Bartlesville pool will approximately follow the average decline curve shown in figure 4, but if selection be limited to properties that during the first year averaged less than 10 barrels daily per well, there will be little likelihood of the property chosen deviating far from the average decline of 10-barrel wells.

Some of the curves rise toward the end of their lives because of the abandonment of some of the less productive wells on a property, thus raising the average production per well.

USE OF LOGARITHMIC COORDINATE PAPER.

Composite curves may be shown on either rectangular or logarithmic coordinate paper. The author has found the latter advantageous in studying production curves, as many production records of individual wells and also many composite decline curves can be made to approach straight lines when plotted on it. This fact has many advantages. For instance, the curve may be projected more easily and accurately, and in the later life of the well when the output of the well becomes small, the curve is projected into an area on the logarithmic paper where the scale is large and more easily read. The reduction of production curves to their algebraic equations is also much simplified by the use of such paper. Figure 4 is an excellent example of curves plotted on logarithmic coordinate paper. When plotted on such paper an equation of the form $y=cx^n$ will be represented by a straight line whose slope is n.

COMPOSITE DECLINE CURVES.

DATA NECESSARY FOR CONSTRUCTING CURVES.

In constructing composite decline curves one should use only the production data of those properties whose output is not materially affected by the rate of drilling. If production is upheld by drilling, the curve for that property is drawn out to a much greater length, and its decline should not be considered in constructing the average curve for the field. The effects of rate of drilling have already been discussed.

WHEN RATE OF DRILLING IS NEGLIGIBLE.

In fields like the Glenn pool where the wells are spaced closely, communication between wells is easy, and, if the sand is porous, the rate of drilling on different properties may be practically ignored. Thus all properties may be used in constructing the average, regardless of whether wells were drilled after the first year. In a field where spacing is not so close, however, or where the sand is thicker, or where any condition exists that materially reduces the rapidity of interference between wells, some consideration must be given the rate of drilling—as, for example, to records of properties in the San Joaquin Valley district (Cal.), where the initial productions are large and the sand is thick, so that the wells decline slower than in a district where conditions are not so favorable. However, records of the production of individual wells can be used. Some of the fields in Illinois are comparable to the Glenn pool. In fact, the author has found, in constructing composite decline curves of the different fields, that where production data are not available for individual wells, the rate of drilling can be ignored in practically every case, except in such fields as those of the Gulf coast and of California, and where wells are pumped down to a few gallons a day, as in the Appalachian region, where the production is so small a new well will materially increase the average daily production as compared with the first year's production.

PRODUCTION BY MONTHS NOT NECESSARY.

The author made no attempt to obtain production records by months except in the Gulf coast and the California fields, because constructing monthly decline curves for different fields would involve a tremendous amount of labor. Moreover, various irregularities in output, such as those caused by winter weather, variations in pipeline runs, etc., are averaged out by taking the output for the whole

year and determining the average produced during each day. Therefore, the annual production for each property was obtained when it was not possible to obtain the annual production for each well, and the average number of wells producing each year was also determined. Often this figure could be determined only by obtaining the dates of completion of these wells, computing the number of wells producing each month, and thus obtaining the average number producing during the year.

CONSTRUCTION OF CURVES.

CURVE FOR A SINGLE PROPERTY.

In making the computations, if a property began producing after July the first year, the output during that year was ignored and the next year's output was called 100 per cent. If, however, the production began during the first six months of the year, that year was called 100 per cent. Obviously a slight error is thus introduced, but it is believed that with a large number of properties the errors will balance. One may use monthly productions if he desires, or those for any other period that will serve best, to show the average decline of a group of properties. For instance, the average daily production could be computed for each half year or for periods of two or three years. The latter unit might be selected for some of the wells in the McKittrick field (Cal.), where the daily output of a well sometimes increases for two or three years after the completion of the well.

CURVE FOR A GROUP OF PROPERTIES.

To obtain the average decline for a group of properties the yearly percentage decline of the properties is determined. The average is then taken for the first year's percentage of all the properties (in this case 100 per cent) and then for the second year's percentage, and so on. This procedure naturally involves many more wells than properties. The first part of the composite, or average, curve thus obtained is usually more accurate than the last, because many of the properties began producing later than others, and therefore had not as long a decline. For example, a property that began producing in 1907 would show a record of 11 years if 1917 is counted, whereas another property that began producing in 1913 would have produced only five years. The percentage for these two properties would be averaged together for the first five years, but after that time the average decline curve would be the same as that of the property that began producing in 1907. This fact is exemplified in

the following table, which also shows the method by which the mathematical averages were determined:

TABLE 1.—*Tabulation of statistics showing the method used in computing the percentages for a composite decline curve.*

Property.	Average daily production per well during first year.	First year.	Second year.	Third year.	Fourth year.	Fifth year.	Sixth year.	Seventh year.	Eighth year.	Ninth year.	Tenth year.	Eleventh year.
	Bbl.	*Per cent.*	*Per cent.*[a]	*Per cent.*[a]	*Per cent.*[a]	*Per cent.*[a]	*Per cent.*[a]	*Per cent.*[a]	*Per cent.*[a]	*Per cent.*[a]	*Per cent.*[a]	*Per cent.*[a]
A	22	100	64	34	22	14	9	5	3	2	1	......
B	3	100	68	54	42	28	36	22	......	......	......	......
C	5	100	68	46	30	17	14	9	......	......	......	......
D	6	100	66	30	13	12	9	......	......	......	......	......
E	2	100	65	40	30	......	......	......	......	......	......	......
F	3	100	57	24	16	16	14	13	13	......	......	......
G	4	100	36	24	11	......	......	......	......	......	......	......
H	13	100	78	34	15	10	5	4	3	......	......	......
I	7	100	65	51	26	19	13	7	7	6	......	......
J	13	100	69	45	21	19	17	13	11	10	......	......
K	41	100	41	11	5	5	3	1	1	1	......	......
L	118	100	15	12	4	2	2	1	1	......	......	......
M	8	100	40	38	37	18	9	7	3	3	......	......
N	8	100	49	39	24	13	12	10	8	4	......	......
O	11	100	42	26	16	10	7	4	2	......	......	......
P	28	100	53	36	13	10	8	6	5	6	......	......
Q	5	100	63	53	37	21	15	10	8	6	......	......
R	5	100	62	36	24	18	10	11	9	......	......	......
S	7	100	63	38	25	20	18	14	10	7	......	......
T	10	100	73	33	19	12	7	8	5	4	2	1
Average	16	100	56.8	35.2	21.5	14.7	11.6	8.5	5.9	4.9	1.5	1

[a] Expressed as a percentage of the first year's average daily production per well.

Another source of inaccuracy in decline records is the abandonment of wells having a small output, for this increases the average daily production of those remaining. Because of this and other occasional irregularities many of the curves shown in part 2 are the result of drawing a smooth average curve through the plotted points instead of actually joining these points with lines. The reader should note the difference in the rate of decline of wells of large and of small yearly initial outputs in Table 1.

APPRAISAL CURVES.

GENERAL STATEMENT.

The term "appraisal curves" was first used by Lewis and the present author,[a] and was applied because of the use of the curves in determining the amount of oil that may be expected from a given area of land, which is one of the most important factors in appraising the monetary value of an oil property.

[a] Lewis, J. G., and Beal, C. H., Some new methods for estimating the future production of oil wells: Am. Inst. Min. Eng., Bull. 134, February, 1918, pp. 477–504.

From a review of the present methods of estimating future production one can see that the most profitable research has been the preparation of percentage curves showing the decline in output of a well or a property. The computed average daily production per well the first year is called 100 per cent, and the corresponding amounts for succeeding years are expressed as percentages of that amount. The future production is then estimated by the projection of the curves. In spite of the progress made there is obvious need of more exact and easily applied methods from which the probabilities and the limitations of the accuracy of the estimates may be determined.

The outline of the following method describing the preparation and use of appraisal curves was first published by Lewis and Beal.[a] The description of the method will be repeated for the sake of clarity, and several methods for the application of such curves will be presented in this paper. The appraisal curve used for illustration is for the Clark County and Crawford County fields (Ill.). Similar curves for other fields are given in part 2 of this bulletin.

DERIVATION AND CONSTRUCTION.

MAXIMUM, AVERAGE, AND MINIMUM CUMULATIVE PERCENTAGE CURVES.

Briefly, the principle of the appraisal curve is based on the difference in the rate of decline of wells of large and of small initial yearly output. The curves printed herein were constructed by using the percentage decline curves of as many properties as are available. Statistics for these decline curves were collected, plotted on prepared forms, and curves drawn through the plotted points. The curves were projected and cumulative percentage curves were constructed that gave the total percentage of oil produced to the end of any year. Thus, if the average daily production per well was, first year, 25 barrels; second year, 15 barrels; third year, 10 barrels; the percentage record would read 100 per cent, 60 per cent, and 40 per cent, respectively. These figures, when plotted, determine the percentage decline curve.

To obtain the cumulative percentage curve with the same figures, the cumulative percentage for the first year would be 100 per cent; for the second year, 160 per cent; for the third year, 200 per cent; and so on. The projection of this cumulative percentage curve to the point where the well reaches its minimum economic production gives the ultimate cumulative percentage; the percentage expresses the ultimate production as compared with the first year's production and is identical with the factor called "volumetric content" by Requa.[b]

[a] Lewis, J. O., and Beal, C. H., Some new methods for estimating the future production of oil wells: Am. Inst. Min. Engr., Bull. 134, February, 1918, pp. 477–504.

[b] Requa, M. L., Methods of valuing oil lands: Am. Inst. Min. Eng., Bull. 134, February, 1918, p. 410.

Using this factor, the appraisal committee of the Independent Oil Producers Agency of California computed ultimate production by multiplying the first year's average daily production per well by 365—the number of days in a year—and then by the "volumetric content." In the present paper the term "ultimate cumulative percentage" is used instead of the somewhat inadequate term applied by Requa.

APPRAISAL CURVE FOR ROBINSON POOL (ILL.).

The appraisal curve in figure 5 was drawn by plotting on rectangular coordinate paper the ultimate cumulative percentage statistics of all the available properties in the Robinson pool, in Crawford County and Clark County (Ill.). The average daily production per well the first year is shown at the bottom of the figure, and the ultimate cumulative percentage is shown on the left margin of the figure. As the ultimate cumulative percentage was plotted against the average daily production per well the first year, each dot represents the ultimate cumulative percentage of a property having a certain average daily output per well the first year.

Then the maximum cumulative percentage curve (fig. 5) was drawn so that practically all properties represented lay below it, and the minimum cumulative percentage curve was drawn to bound the bottom of the area occupied by the dots. The average cumulative percentage curve was drawn as a mean between these two extremes, although an attempt was first made to determine this average by computing the mathematical average of all the properties in several different successive segments of the area bounded by the maximum and minimum cumulative percentage curves. However, the curve determined in this manner was so close to the actual mean between the maximum and minimum that in most of the other appraisal curves constructed the actual mean was taken. Possibly this may be a mistake. The conditions affecting production may be such that the actual average curve in some fields may be above or below the mean. In fact, in the appraised curve for the Osage Indian Reservation (Okla.), the numerical average was obtained and was found to be considerably below the mean. But this average curve should not be considered as a mean on the left side of the chart because all three curves approach the y-axis at infinity, and as the average cumulative percentage curve nears the left margin of the chart it approaches the minimum cumulative percentage curve.

Although the fact of the curves meeting at infinity along the vertical line representing zero production has no great practical importance, it nevertheless establishes the interesting deduction that the smaller the initial output of a well, the smaller will be its ulti-

mate output and the larger its ultimate cumulative percentage. This deduction indicates that, on the average, the smaller the well the slower its rate of decline. As a matter of fact, a well whose initial

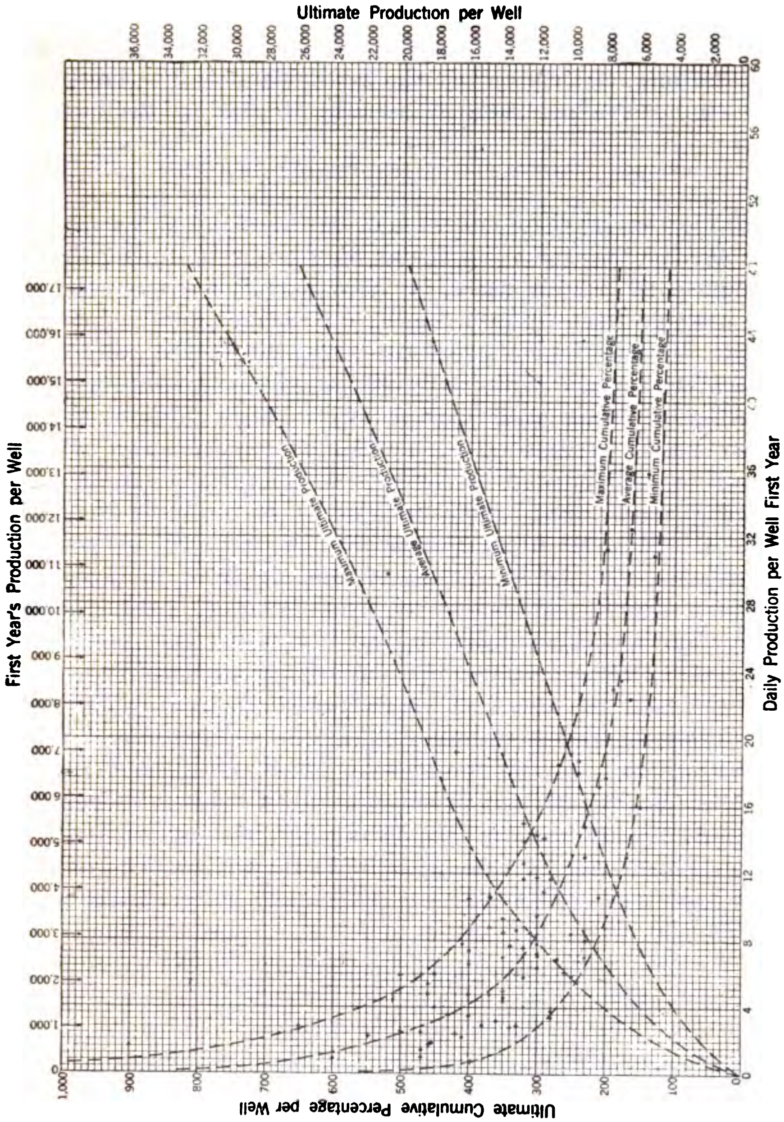

FIGURE 5.—Appraisal curve of the Crawford and Clark County fields, Ill. The dots represent the ultimate cumulative percentages per well of properties in the Crawford County field and the crosses represent the corresponding percentages per well of properties in the Clark County field. Production figures are in barrels.

production is below the minimum profitable production would not be pumped, so that the three curves indicated as approaching infinity would, in fact, reverse themselves at the line representing the minimum profitable production and join at zero. In the preparation

of this and all other appraisal curves, however, the maximum, average, and minimum cumulative, percentage curves have been drawn to approach the y-axis at infinity. Although the ultimate production of a large well is greater, its ultimate cumulative percentage is much less than that of a small well; the larger wells, as the chart shows, tend to have small ultimate cumulative percentages, because of rapid declines, and conversely the small wells tend to have large ultimate cumulative percentages, because of gradual declines.

USE OF ULTIMATE CUMULATIVE PERCENTAGE CURVES.

The application of these curves may be shown by an example, as follows: Assume that the average well on a property during the first year produces 20 barrels daily, or 7,300 barrels for the year, and that the average future production of a 20-barrel well in that pool is desired. Follow the 20-barrel line vertically to the point where it intersects the average cumulative percentage curve, then trace from this intersection horizontally to the left. The reading is 197 per cent; that is, the average ultimate cumulative percentage of a 20-barrel well is 1.97 times its first year's production, or, in this case, about 14,400 barrels. But 7,300 barrels have been produced during the first year, therefore the future output of the well will be 7,100 barrels. Similarly, the maximum that this well will produce is obtained by following the 20-barrel line vertically to the maximum cumulative percentage curve and thence to the left, the figure thus obtained is 255 per cent. In other words, the maximum that such a well will produce is 2.55 times the first year's production, or about 18,600 barrels. Likewise, the minimum yield of the well may be obtained from the minimum cumulative percentage curve, which indicates 1.4 times its first year's production, or about 10,200 barrels. Therefore, the average 20-barrel well in this pool, after its first year will not make *more than* 11,300 barrels (18,600–7,300), will make *on an average* 7,100 barrels (14,400–7,300), and will make *at least* 2,900 barrels (10,200–7,300).

ULTIMATE PRODUCTION CURVES.

DERIVATION OF CURVES.

Although the ultimate cumulative percentages are less for the wells of larger output, the actual ultimate production of such wells is greater and usually varies with the initial yield, as is shown by the maximum, average, and minimum ultimate production curves in figure 5. These curves were plotted to bring out this relation and were derived directly from the ultimate cumulative percentage curves by multiplying the first year's production of wells of various initial

yearly capacities by their respective ultimate cumulative percentages. In other words, these three curves were derived from the maximum, average, and minimum cumulative percentage curves by choosing different initial productions (daily per well the first year) and multiplying by 365 (days in a year) and by the respective ultimate cumulative percentages. The same curves might have been prepared by plotting the estimated ultimate production per well against its initial yearly output, basing the curves on actual output and estimated future production instead of deriving them from the percentage curves. By using the ultimate production curves instead of the ultimate cumulative percentage curves, an estimate of the ultimate and future production of a well may be obtained much more rapidly and easily.

APPLICATION OF CURVES.

Take the example already cited; that is, a well on a property averages 20 barrels a day the first year. What is its probable future production? Following the 20-barrel line to the points where it intersects the three different ultimate production curves and thence to the right margin, shows that the maximum, average, and minimum ultimate productions of such a well are 18,600, 14,400, and 10,200 barrels, respectively. These estimates are the same as those obtained by using the maximum, average, and minimum cumulative percentage curves. To determine the actual future production, the first year's production ($20\times365=7,300$) is subtracted from the estimates of ultimate production; the differences are 11,300, 7,100, and 2,900 barrels, or the same values as those obtained by the previous method (p. 34). It will be seen that the percentage deviation of the extremes (or limits) from the average ultimate production is 29—that is, if this method of determining ultimate production were used, the possible deviation from the average, according to the histories of the wells upon which these curves are based, would be not more than 29 per cent. The percentage deviation from the average actual future production, however, would be greater. A study of the decline of the wells during the months of the first year would yield a closer estimate, for the monthly figures would indicate whether the wells would approach the maximum or minimum curves.

Two different districts are represented in figure 5. Most of the properties shown lie in Crawford County (Ill.), but a few are in the shallower Clark County district, a few miles north. Because of this difference in the depth of the sands there is a slight difference in the decline of the wells, so that the ultimate cumulative percentage of a property in one of the fields differs a little from that of one in the other. The ultimate cumulative percentages of the properties in Clark

County are therefore shown by crosses and those of the Crawford County district by dots. The crosses tend to approach the upper limits of the area bounded by the maximum and minimum cumulative curves, hence a person using the chart for estimating the ultimate or future production of properties in Clark County should take this fact into consideration. The lower limit, defined by the minimum cumulative percentage curve, is the same for both districts. The average curve, like the maximum, is a trifle higher than that shown.

Curves may be prepared on this same chart to show the actual future production for wells of different initial production, the first year's production being deducted from the determined ultimate production and the remainder being plotted. By the preparation of such a curve one may read directly the actual future production of wells of any output.

USE OF APPRAISAL CURVES.

BASIS FOR USING.

The use of appraisal curves in determining future output is based on the average daily production per well on a property during the first year. However, if a property were, for example, four years old, it would be advantageous, because of fewer calculations or lack of data, to take the most recent year's output in determining future production. But the curves given can not be used thus unless the average future production of wells of equal output in the same district is approximately the same. This "law of equal expectations" has been shown to be true in a previous publication.[a] Data collected more recently confirm absolutely this law which may be restated as follows: "*If two wells under similar conditions produce equal amounts during any given year, the amounts they will produce thereafter, on the average, will be approximately equal regardless of their relative ages.*" The law applies particularly to the output of wells that have become "settled."

After an estimate of future output has been made as outlined above, it can be made more nearly accurate by determining from the first four years' production whether the property follows the average, the maximum, the minimum, or some combination curve. In other words, to determine the future production use the last year's production on the appraisal curve and modify the results thus obtained according to whether the action of the wells during the past four years indicates that the well ranks above or below the average well.

[a] Lewis, J. O., and Beal, C. H., Some new methods for estimating the future production of oil wells: Am. Inst. Min. Eng., Bull. 134, February, 1918, pp. 477–504.

ADVANTAGE IN USE.

the appraisal curve to determine future production makes
ry the employment of a composite decline curve which, from
the average decline of wells of all sizes, as cited on page
an estimate too large for large wells and too small for
lls. By preparing appraisal curves applicable to a district
e or ultimate production of wells of any size or age can
ined at once.

to determine the limitations of estimates of future or ulti-
luction is important. From a composite decline-percentage
s impossible to determine how large the maximum produc-
be or how small the minimum. By the use of appraisal
owever, it is a simple matter to determine at once the
and the minimum amounts of oil that may be expected.

ACCURACY OF APPRAISAL CURVES.

he appraisal curves, with the first year's production of a
roup of wells given, it is possible to determine both the
and the maximum amounts of oil that probably will be
and also the amount that the average well of a certain
rly output will ultimately yield.

CARE TAKEN IN COMPILING DATA.

of the actual performance of wells were used in preparing
enough trustworthy records having been taken to insure
rves marked "average" represented the actual average per-
of many wells or properties, unless the conditions were
hanged later, as drilling into a deeper sand.

l wells were omitted in making this and other similar charts.
of course, extraordinary wells whose production would not
l with that indicated on the chart. Some wells, for example,
a decreasing daily yield show a sustained or even an in-
aily output for several years. Other wells may cease pro-
ldenly and, perhaps, begin again after many months or
sudden increase in the production of old wells is not
nd the termination of the life of a well by accident or by
tion of water is rather common. The futility of estimating
production of such freakish wells is obvious.

at advantage of the method is that the ordinary irregu-
common in wells on many properties, disappear by aver-
r instance, using yearly productions instead of daily pro-
nd averaging several wells on a property, eliminate the
ies of any well whose yield fluctuates rapidly. Thus,

figure 5 represents the production of 83 properties, including about 900 wells, so it is evident that the uncommon wells have little influence even though they were on a property that was used in preparing this chart.

RELIABILITY OF ESTIMATES MADE FROM CURVES.

In view of the derivation of the data and the systematic manner in which they arrange themselves when plotted to show how ultimate cumulative percentages compare with initial yearly productions, it is believed that much reliance may be placed on such curves. Not only can the appraisal curve in figure 5 be used with confidence, but estimates of future and ultimate production of properties in other fields may be made by the use of similar charts to be presented later (see figs. 24 to 70). In practically any field, where the conditions affecting production are not too diverse, such curves can be prepared and can be used confidently. The less diverse the conditions that affect production, the closer the maximum and the minimum limits will be to the average curve, so that future and ultimate production can be estimated much more closely than in fields where the conditions have a wide range. For instance, the table on page 205 shows the percentage of deviation above and below the average for the estimates of future production in some of the fields for which appraisal curves have been made.

APPRAISAL CURVES DIFFICULT TO PREPARE FOR SOME DISTRICTS.

For districts like the San Joaquin Valley fields in California the preparation of appraisal curves is difficult because the conditions affecting production vary decidedly. Figure 6 shows the wide variation of the ultimate cumulative percentages for several wells selected at random in the West Side Coalinga field (Calif.). Because of these variations, the wells used in preparing an appraisal curve must be selected with care and from areas where the conditions affecting production are similar.

RELATION OF INITIAL PRODUCTION TO ULTIMATE CUMULATIVE PERCENTAGE.

Figure 5 (p. 33) shows that the ultimate cumulative percentages vary considerably for wells of different daily production the first year, and that the smaller the output of the well during the first year the greater the variation of the ultimate cumulative percentages. For instance, for a well averaging 4 barrels daily the first year, the ultimate cumulative percentage will vary between 270 and 555, whereas, for a 40-barrel well the variation is only 118 to 193. Conversely, the

larger the ultimate cumulative percentage of a property, the narrower will be the limits of the possible initial production. Thus, a property whose ultimate cumulative percentage is 550 will have a daily pro-

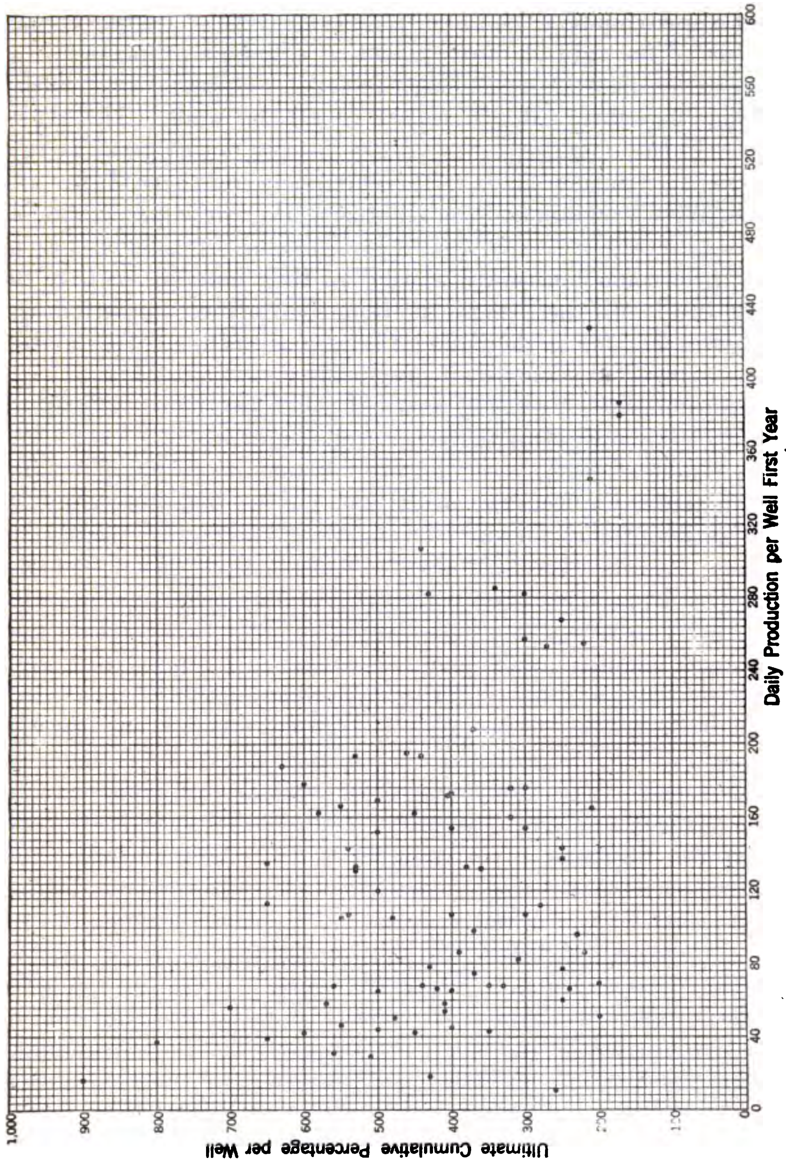

FIGURE 6.—Chart showing the ultimate cumulative percentage of several wells in the West Side Coalinga field, Cal. Production in barrels.

duction per well the first year of 0.2 to 4 barrels, but a property whose ultimate cumulative percentage is 200 will have a daily production per well the first year of 9 to 34 barrels.

POSSIBLE SOURCES OF ERROR IN CONSTRUCTING CURVES.

One source of error that occasionally may have to be considered, if records of individual wells are not available, or if all wells were not drilled at approximately the same time, is the rate of decline changing because of the rate of development of different properties. On some properties the wells drilled later retard, by their initial "flush" production, the actual rate of decline of all the wells. The errors introduced in this manner, however, are usually not as great as supposed, especially in such fields as the Oklahoma, northern Texas and Louisiana, West Virginia and the Illinois, as the initial production of new wells near old ones tends strongly, because of interference or drainage, to become constantly smaller as time goes on, so that the new wells drop into the general average soon after completion and may be ignored as far as they affect the rate of decline. This matter has been discussed in some detail previously (pp. 21 to 24).

The abandonment of wells of smallest yield also tends to keep up the average daily output of the other wells on a property, and often more than doubles their average production. Occasionally abandonment noticeably affects the production curves, as is shown in figure 4 (p. 26) by the composite curves during the eighth, ninth, and tenth years. Another source of error in constructing the curves is the minimum limit to which nearly exhausted wells can be pumped with profit. An increase in the price of oil may raise this limit so that wells of much smaller output may be profitably pumped. For wells of large initial yield this additional production will be so small compared with the first year's output that the error in the cumulative percentage is negligible, but for wells of small initial yield the error may be of some magnitude. Other sources of error are the alterable factors of recovery—such as manner of operation, "shooting," and the application of compressed air, vacuum pumps, or water drive—which may cause changes in the ultimate production and the rate at which the oil is recovered. These changes will increase the ultimate production as well as the rate at which the oil is obtained, but their effects, especially during the later life of a well, may usually be ignored as far as any great variation of ultimate production is concerned, although there may be a noticeable change in the rate at which the remaining recoverable oil is extracted.

The damaging effect of water invading the productive sand is to be noted. Occasionally a young field of much promise will be greatly damaged by water. The water may encroach naturally or be let into the sand by careless operators.

DETERMINING THE MAXIMUM, AVERAGE, AND MINIMUM RATES OF DECLINE OF WELLS.

VALUE OF KNOWING RATES OF DECLINE.

The author has discussed the use of appraisal curves in determining the ultimate and future production of oil properties producing under certain given conditions. A knowledge of the amount of oil that may be obtained in the future is important and valuable, but information on the rate at which this oil will probably be obtained—that is, the future annual production—is still more important. With this knowledge the operator can easily estimate his yearly income from the property by assuming a certain price per barrel for oil and a certain drilling program. Fortunately, to determine, through the use of appraisal curves, the future annual production of a property is not difficult.

Not only can one determine the probable average future production, but one can also obtain an excellent idea of the maximum and minimum rates of yield. The possibility of determining these maximum and minimum limits, as well as the average rate, greatly extends the use of the appraisal curves, for in such determinations lies the crux of the valuation of oil properties.

DECLINE OF A WELL IN THE CLARK COUNTY AND CRAWFORD COUNTY FIELDS, ILLINOIS.

Take, for example, a property in the Clark County and Crawford County fields (Ill.), on which the average well during the first year produced 10 barrels daily. To determine the average decline of such a well, follow the 10-barrel line in figure 5 (p. 33) to the average ultimate-production curve and thence to the right; the ultimate production is 10,100 barrels. This figure includes the first year's production of 3,650 barrels; deducting that leaves a future production of 6.450 barrels. Reversing the process and reading from the right margin horizontally to the left along the line representing 6,450 barrels to the point where this line intersects the average ultimate-production curve and thence reading downward, one finds that a well whose ultimate production is 6,450 barrels will produce during the first year 1,680 barrels, or 4.6 barrels a day. Deducting 1,680 from 6,450 gives a future of 4,770 barrels, which in turn is the ultimate production of a well producing 1,020 barrels the first year, or 2.8 barrels a day. These calculations may be continued until the original 10,100 barrels are exhausted. The yearly production of the average decline curve for a 10-barrel well is therefore, successively, 3,650, 1,680, and 1,020 barrels for the first three years.

In a similar manner maximum and minimum decline curves may be constructed by determining the intersection of the line, representing 10 barrels a day the first year, with the respective maximum and minimum ultimate production curves. In this way one may determine the average rate of decline of a 10-barrel well and also the maximum and minimum rates at which the oil may be obtained. There is little likelihood of a 10-barrel well in Clark and Crawford Counties (Ill.) declining more rapidly than the maximum decline curve or more slowly than the minimum decline curve.

If a property has been producing some years, and one wishes to determine the average rate of decline of the future production, the same process is used, but the future curve itself is modified in accordance with the rate of yield of the well during the first few years of its life. In other words, the average well on a property may decline slower or faster than the average decline curve would indicate for a well of that output; then the future annual production should be modified.

METHODS OF MAKING CLOSER ESTIMATES.

EFFECT OF DIFFERENCES IN INITIAL OUTPUT OF WELLS.

In the preparation of figure 5 (p. 33) the average daily production per well the first year was plotted against the ultimate cumulative percentage for each property of the district. It has been shown that by constructing the appraisal curves from these data certain definite limits to estimates of future and ultimate output can be obtained. Although the author has already found the chart of much value, refinements are desirable that will define more closely and with fewer data the probabilities of wells at earlier periods in their lives.

As has been shown, wells of the same initial yearly production may ultimately yield widely differing amounts of oil, and, conversely, a certain ultimate amount of oil may be produced by wells of widely varying initial yearly output. These variations are not without cause, and it is believed that a systematic study of the factors influencing production will result in materially reducing the limits of the estimates of future and ultimate yield. For instance, on figure 5 are shown the ultimate cumulative percentages of properties in two different fields in Illinois. The percentages of properties in the Clark County field, shown by crosses, generally lie higher than the ultimate cumulative percentages of properties in the Crawford County field.

Moreover, closer study may permit curves derived from the production data of one field to be applied with more confidence to a new field. Assembling enough data may show that in one pool a well making 20 barrels daily during the first year with a certain gas pres-

sure would nearly always be above the average in that pool or, if the wells were spaced a certain distance apart, the tendency would be above or below the average for wells of that size. Undoubtedly, some of the factors that influence the production of many wells are of so little consequence that they may be neglected. The character of the production curve, however, is determined by the synthetic influence of several factors, and the effect of any one varies with the local conditions in each field.

Other factors, in addition to the initial output, that may profitably be studied are the area allotted each well and the depth and thickness of the producing sand. Other less important factors are gas pressure, the character of the oil sand, and the quality of the oil.

EFFECT OF ACREAGE PER WELL.

An attempt has been made to narrow the limits and thus enable closer estimates of future and ultimate production by using some of these factors. Enough information was obtained, however, for only such factors as acreage per well and depth and thickness of the sand. No attempt was made to utilize the scattered information on geologic structure, the character of the oil sands, or the quality of the oil. Figure 7 was prepared by selecting all those properties in the Crawford County field (Ill.) for which the acreage per well could be determined with fair accuracy. The same ultimate cumulative percentages for each property were used as in preparing figure 5. In figure 7 the dots that represent ultimate cumulative percentages for certain acreages per well seem to arrange themselves consistently in an area that ascends to the right. In other words, the greater the acreage each well drains the greater is the ultimate cumulative percentage of the well. This fact is so evident as to need no proof; a well draining a large area should decline slower and produce longer than one draining a small area.

To illustrate the use of figure 7, assume that a well in the Crawford County field drains 6 acres; the maximum, average, and minimum cumulative percentages of that well therefore will be, in order, 355, 275, and 200. Similarly the minimum ultimate cumulative percentage of a well that drains 9 acres of sand is 300 per cent.

EFFECT OF THICKNESS OF OIL SAND.

In the same manner the ultimate cumulative percentages of different properties in the Crawford County field were plotted against the average thickness of the oil sand under each property (fig. 8). The limits thus established were by no means so narrow as those obtained by plotting ultimate cumulative percentages against acreage per well,

for it is difficult to determine exactly the total thickness of a producing sand. Also, it is difficult in this case to determine accurately where the maximum and minimum limits should be drawn. However, the

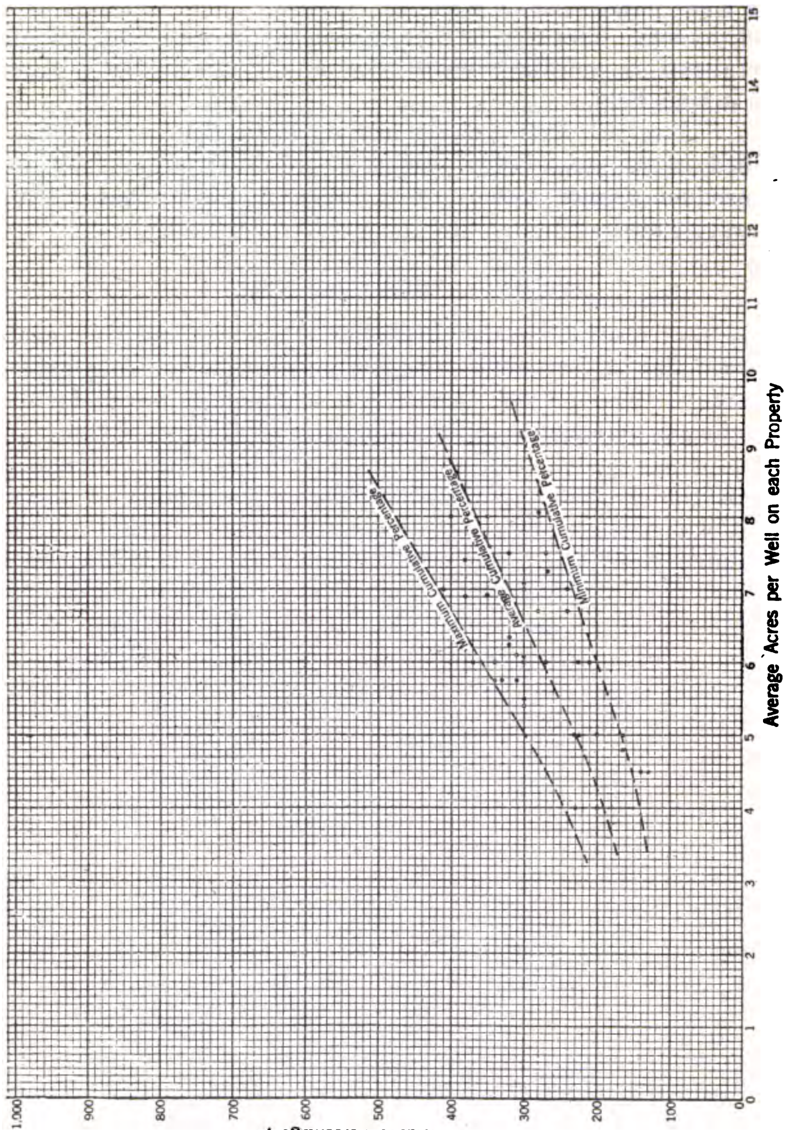

FIGURE 7.—Chart showing the relation of acreage per well to ultimate cumulative percentage in the Crawford County field, Ill.

thickness of sand was taken as the average thickness reported in the different wells on each property. Examples to be given later show that even these limits are occasionally of material aid in making closer estimates of future and ultimate production.

Figure 8 demonstrates the well-known fact that the thicker the sand the slower the rate of decline of the wells draining it, as the three curves gradually rise to the right. In other words, the thicker the

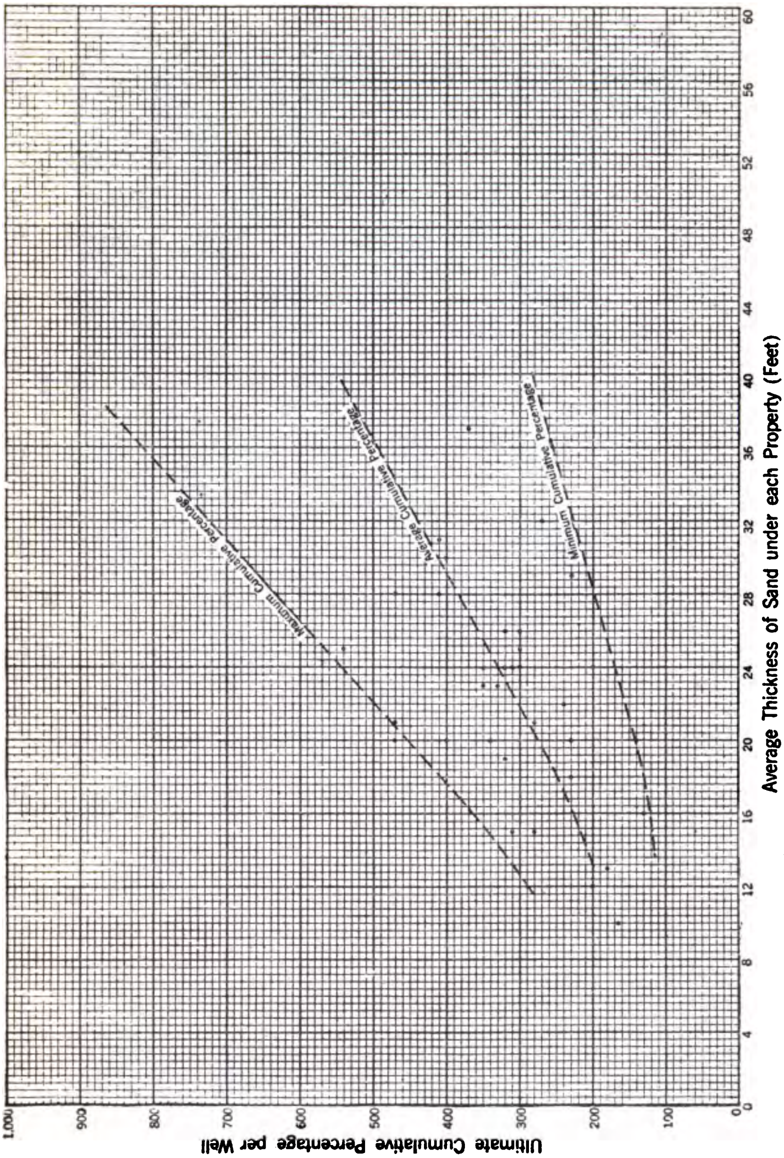

FIGURE 8.—Chart showing the relation of average thickness of sand to ultimate cumulative percentage in the Crawford County and Clark County fields, Ill.

sand the higher the ultimate cumulative percentage, for the decline of wells draining thick sands is ordinarily slower than that of wells drilled into thin sands.

EFFECT OF DEPTH OF OIL SAND.

The third method employed for reducing the limits is shown in figure 9, which gives the limits determined by plotting ultimate

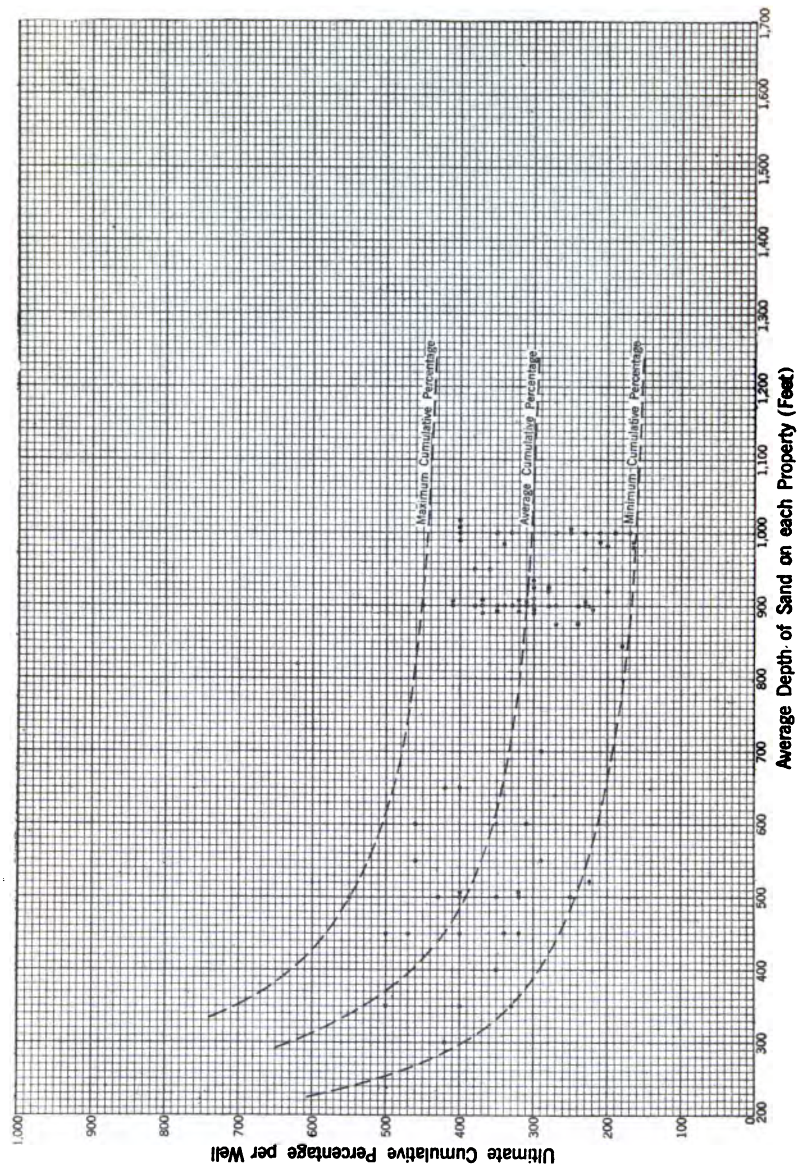

FIGURE 9.—Chart showing the relation of average depth of sand to ultimate cumulative percentage in the Crawford County field, Ill.

cumulative percentages against the average depth of the oil sand on each property. This figure proves the general rule that the deeper the sand the smaller the ultimate cumulative percentage.

NARROWING OF ESTIMATES IN CRAWFORD COUNTY FIELD, ILL.

In figure 10 the ultimate cumulative percentage of each of several properties in the Crawford County field were plotted against four conditions that control the ultimate production and decline of oil

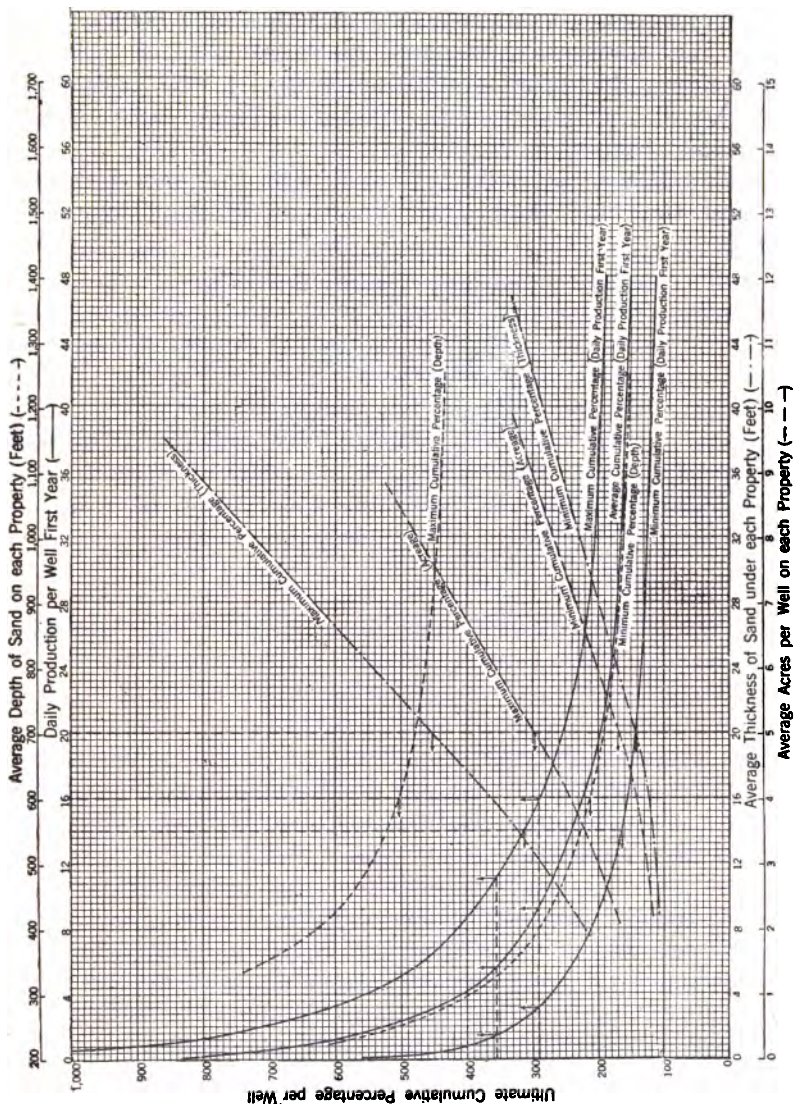

FIGURE 10.—An example of how figures 5, 7, 8, and 9 may be used to make closer estimates of future and ultimate production.

wells, as follows: (1) The average initial production per well (daily production per well the first year); (2) the average acreage per well; (3) the average thickness of sand; and (4) the average depth of the producing sand.

Let us now determine how this new composite chart may be used in making more accurate estimates of the future and the ultimate output of a well that, for example, has been producing one year. The average daily production during the first year is 14 barrels; the wells on the property are being spaced so that they drain approximately 5 acres each; the oil sand is 20 feet thick and 600 feet deep. How can the information prepared in figures, 5, 7, 8, and 9 be used to estimate the future production of such a well more closely than by figure 5, which shows the relation between daily yield the first year and ultimate production?

The table following gives the limits established by each controlling factor and the final determined limits of ultimate cumulative percentage:

Limits of ultimate cumulative percentage.

	Initial production, 14 barrels daily, first year.		Area drained, 5 acres.		Thickness of sand, 20 feet.		Depth of sand, 600 feet.	
	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.
Limits of ultimate cumulative percentage established by each factor..	310	170	295	170	450	140	500	210
Determined limits of ultimate cumulative percentage..................	....	....	295	....	....	....	....	210

Maximum ultimate production, 15,000 barrels; minimum ultimate production, 10,700 barrels.

By the use of figure 10 one finds that a well making 14 barrels a day the first year will ultimately produce a minimum of 170 per cent and a maximum of 310 per cent of its first year's production (shown by arrows). A well draining 5 acres in this field will furnish an ultimate minimum output of 170 per cent and an ultimate maximum output of 295 per cent of its first year's production (shown by arrows). Similarly, a well in the same pool draining a sand 20 feet thick will ultimately produce on the average a minimum of 140 per cent and a maximum of 450 per cent of its first year's production (shown by arrows); and a well 600 feet deep will produce ultimately a minimum of 210 per cent and a maximum of 500 per cent of its first year's production (shown by arrows). Thus, four different minima are established, 170 per cent, 170 per cent, 140 per cent, and 210 per cent. Of these the highest, or 210 per cent, may be selected for making the estimate. In like manner and for the same purpose one selects the lowest maximum percentage, which is 295. Consequently, the final narrowed maximum and minimum limits are 295 and 210 per cent instead of the 310 and 170 per cent obtained by using figure 5 alone in determining the limits. In other words, a well that under the specified conditions of acreage, sand thickness, and depth makes 14 barrels a day the

first year, will produce ultimately a minimum of 2.1 and a maximum of 2.95 times its first year's production.

Without the use of these additional factors for narrowing the limits, the deviation of the minimum percentage below the average is 27.5 per cent, and that of the maximum above the average is about 32 per cent; whereas with all four factors used the deviation of the minimum percentage below the average is about 17 per cent and that of the maximum percentage above the average is about the same. Hence, by using all four factors, the ultimate production of a well of this output can be determined within about 17 per cent. For the 14-barrel well cited the ultimate production is between 10,700 and 15,000 barrels.

By using these factors for narrowing the limits of the estimates, a man knows, judging from the past history of regularly operated wells in this field, that he should not expect a 14-barrel well to yield ultimately, under the most favorable conditions, more than 17 per cent above the average; and that, under the most unfavorable conditions, the ultimate production of the well will fall not more than 17 per cent below the estimated average ultimate output. On the other hand, if a man with no knowledge of these other factors has to estimate the ultimate production of a 14-barrel well, the actual final yield may exceed the estimated average by about 32 per cent or may fall as much as 27 per cent below it.

DETERMINING THE AVERAGE DAILY PRODUCTION FOR THE FIRST YEAR.

GENERAL STATEMENT.

The preceding discussion leads naturally to this question: If one has determined the influence of acreage, of depth, of sand thickness, and of initial yearly output on the ultimate or future production of a well in a certain district, why can he not determine the probable future initial yearly production of a well if he knows the acreage, sand thickness, and depth? These last three factors can readily be determined before the well is drilled, especially if it be situated in a proved district or in one where conditions are like those in a district where data can be obtained.

The ultimate production of a well depends on the initial production, and almost all estimates of the ultimate output of undrilled territory are based in some manner on the early action of the well. Estimating the future production by percentage decline curves rests entirely on the average daily production the first year. In fact, this unknown quantity has been decidedly puzzling and has been an element of uncertainty and error in estimating future output by pro-

duction curves. Drainage or interference of producing wells is an important factor, and its extent, which is a function of time, distance, and gas pressure, greatly modifies the initial production of new wells. The lenticular structure of oil sands and differences in their porosity, as well as other geologic conditions, also affect initial production, and to determine the composite influence of all these factors is extremely difficult.

FACTORS DETERMINING VALUE OF OIL LANDS.

Among the more important factors determining the value of an oil property are (1) the amount of oil that will be ultimately recovered from it, and (2) the amount that will be produced each year. Obviously, if (2) can be determined, (1) may be obtained by adding the annual output during the life of the property. To make trustworthy estimates of the future annual output, one must have (1) some knowledge of the rate of decline of similar producing properties, and (2) either an estimate of the first year's production of each new well, or an estimate of the probable yield per acre of the undrilled area. Often it is more advantageous to estimate future initial yearly production and then by using the decline curve to compute ultimate output, but occasionally estimates of ultimate production are made and the initial yearly output computed, as explained later (pp. 53–55). Clearly, methods for determining the probable initial yearly production of undrilled wells are greatly to be desired.

THE DECREASE IN INITAL YEARLY PRODUCTION.

CAUSE OF DECREASE.

When a well is drilled into an oil sand the oil is expelled through the opening and the pressure in the sand decreases first at the well. This area of lowered pressure gradually extends in every direction at a rate determined by the thickness and porosity of the sand, the viscosity of the oil, the strength of the expulsive force, and other factors. The extent of the area varies directly with the time during which extraction takes place. Within the drainage area, in a sand partly drained in this manner the pressure is always lowered, and another well drilled within that area will have a smaller production, because of the expulsive forces being partly exhausted. In a field that is being drilled, therefore, the drainage areas of the producing wells finally begin to interfere with one another. This interference reduces the gas pressure over large areas and consequently reduces the initial production of new wells, but as long as the new wells are drilled in areas unaffected by drainage, their initial production will not be affected. As a general rule, however, the initial production of wells drilled during the later life of a field are decidedly less than

the initial production of the first wells, so that this condition must be considered in estimating the future output of new wells, inasmuch as ultimate production is influenced by initial production.

IMPORTANCE OF RATE OF DECREASE.

The rate of decline in initial yearly production is of so much importance that it must be kept in mind in drilling to maintain production and in estimating the future output of producing oil properties and the ultimate production of undrilled oil properties. Frequently this decrease in the initial output of undrilled wells is not considered and the assumption is made that all the wells drilled on a certain tract will have approximately the same initial production.

Curves have been prepared showing the decrease in production of new wells drilled during several successive years of several hundred properties in different parts of the country. Some concrete examples (figs. 11, 12, and 13) show declines of the Lawrence County pool (Ill.), the Bartlesville field, the Bird Creek-Flatrock and Glenn pools (Okla.), and the Kurokawa field (Japan). In figure 55 (p. 157) the inset shows the decrease in initial yearly production of several wells in the Caddo field (La.). The figures on each curve denote the number of properties taken to obtain the average daily output per well during that year. In preparing these curves all properties beginning to produce in one year, for instance, 1908, were separated from those beginning in other years, and the average daily production per well for each property was computed for the first year. The curve represents this average for each year. The figures on the curves indicate the number of properties used to determine the average.

DETERMINING INITIAL YEARLY OUTPUT FROM COMPOSITE DECLINE CURVES.

When composite percentage decline curves are used for estimating future annual production, the average daily production of a well during the first year is called 100 per cent. The yearly output of properties after the first year is shown as a percentage of the first year's output, so that the production for any future year may be obtained by multiplying the average daily production for the first year by the yearly percentage indicated by the curve. In this way, if the first year's production of a well is known and if the production of a well will probably decline along a known curve, it is easy to determine the future annual output.

ESTIMATING FROM THE RECORDS OF OTHER WELLS.

In case a well has not produced one whole year, or an estimate of the future annual production of an undrilled well is desired, it is nec-

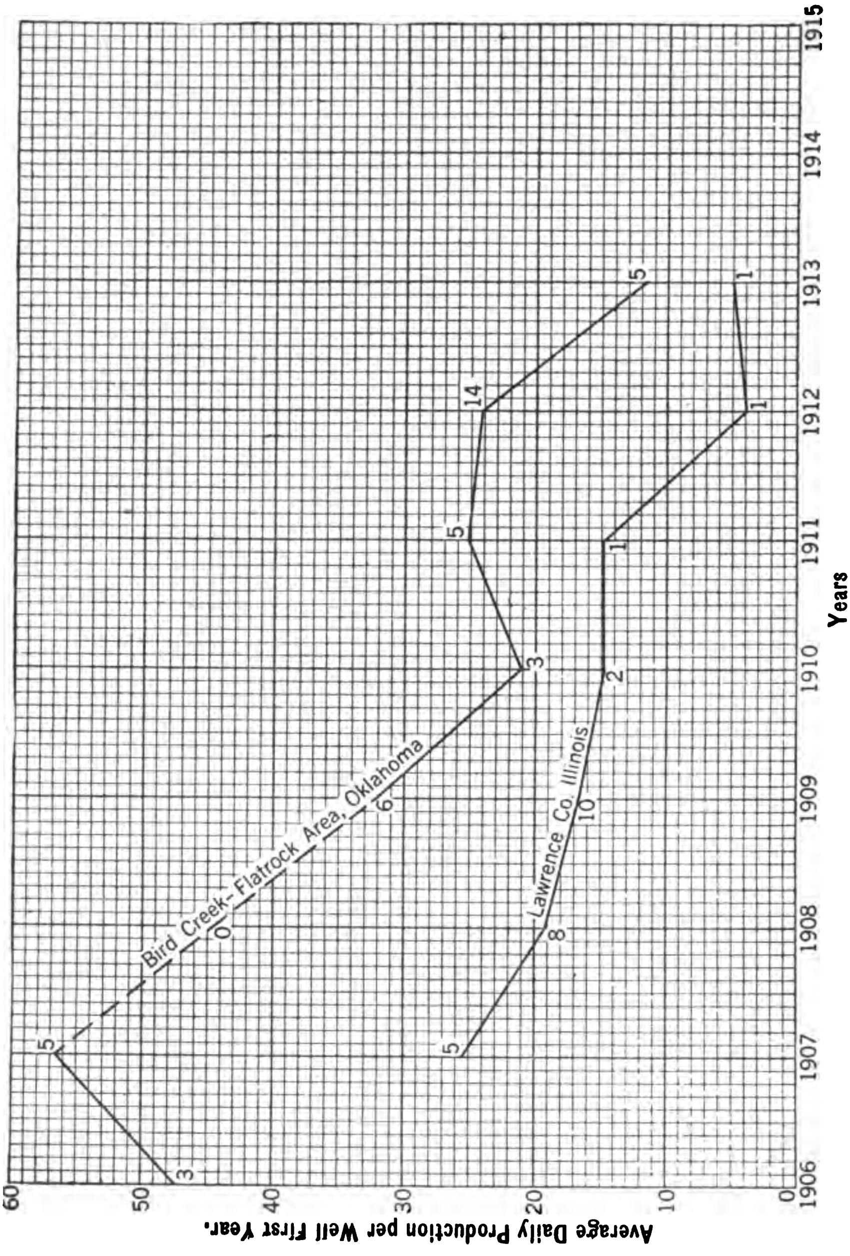

FIGURE 11.—Curves showing the decrease in the daily production (in barrels) the first year of wells on several properties in the Bird Creek-Flatrock field, Okla., and on several properties in the Lawrence County pool, Ill.

essary to assume a certain daily production the first year, unless in the case there is information available to show the relation between the initial output the first 24 hours and the average daily production of a well during the first year. (See p. 59.)

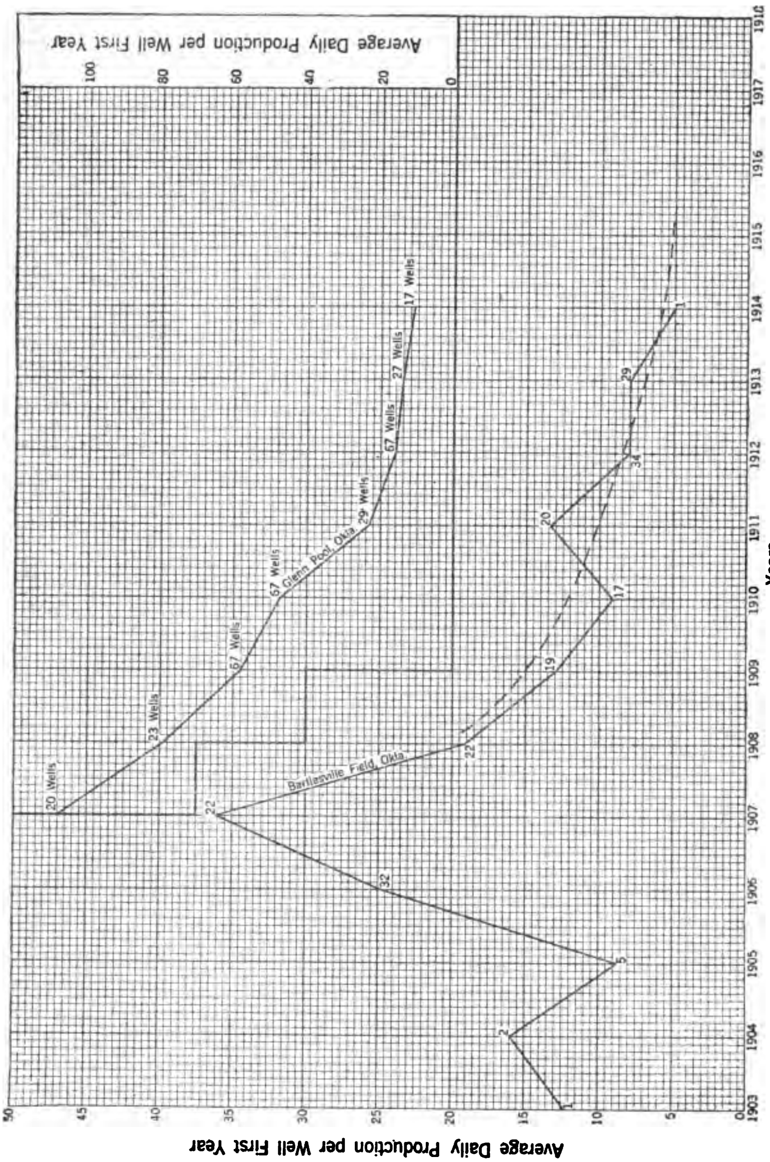

FIGURE 12.—Curves showing the yearly decrease in the first year's daily production (in barrels) of wells on several properties in the Glenn pool and the Bartlesville field, Okla.

ESTIMATING FROM ASSUMPTIONS OF ULTIMATE PRODUCTION.

The first year's daily output may be estimated by assuming a certain ultimate production per acre of the undrilled territory and then

figuring backward. To illustrate the use of this method, assume that a composite decline curve is available, showing an ultimate cumulative percentage of 500; in other words, the ultimate production of a

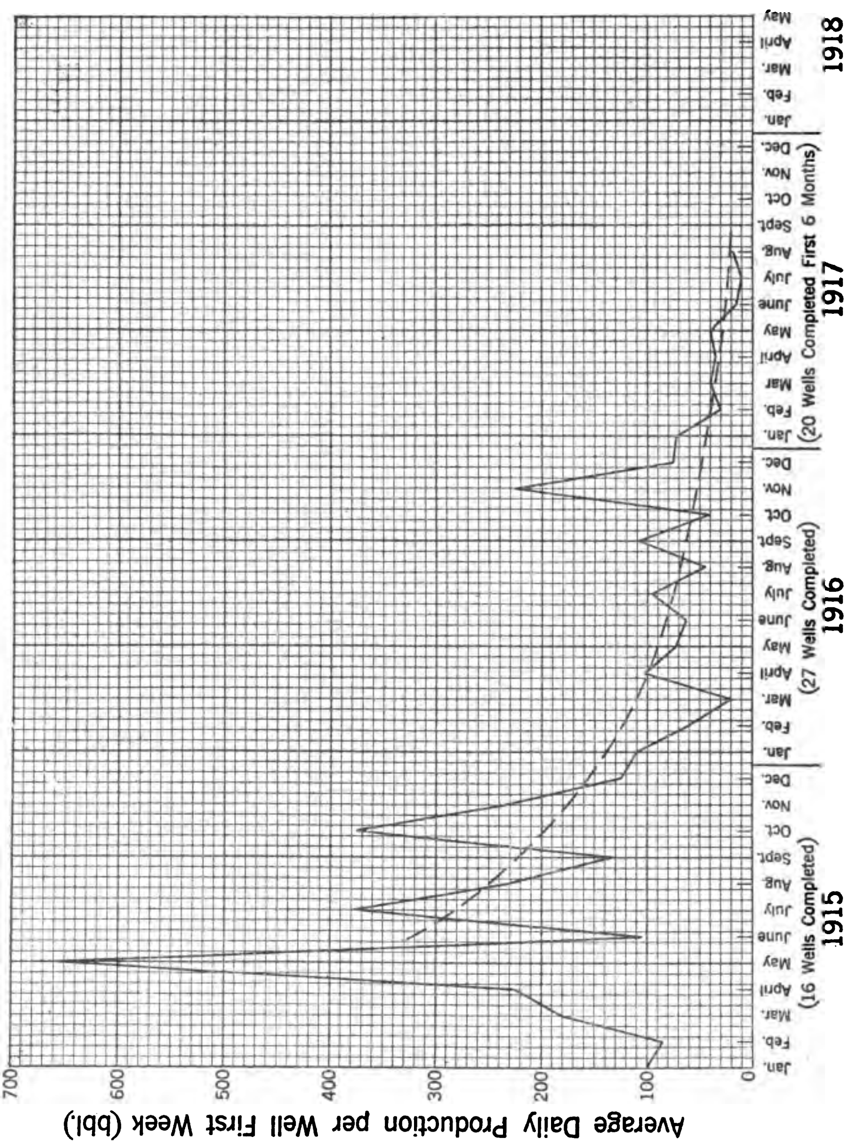

FIGURE 13.—Curve showing the decrease in initial monthly output of many wells in the Kurokawa field, Japan. (Data furnished by the Japanese Geological Survey.)

well following this curve may be estimated by multiplying the first year's production by 5. Assume also that the undrilled area in question will produce ultimately 18,250 barrels per acre and that the wells will be spaced so that each well will drain 10 acres. The average

daily production the first year may be determined by the following equation:

$$\text{Daily production the first year} = \frac{18{,}250 \times 10}{365 \times 5.00} = 100 \text{ barrels.}$$

COMBINATION METHOD.

Sometimes a combination method is used, the initial yearly production being estimated directly and then being checked by estimating the ultimate production per acre and calculating the initial yearly production of the new wells by the method just given.

USE OF APPRAISAL CURVES.

The same kind of estimates may be had by using appraisal curves (fig. 5. p. 33), but these curves have the advantage of giving also the maximum and minimum initial yearly production that may be expected. Essentially, these curves are based on the relation between the ultimate and the first year's production, and with a certain first year's output the annual output can be computed by the method explained on page 34. The ultimate production on the right margin of figure 5 gives the total amount; that is, the average a well with a certain initial yearly production will make.

If the average acreage per well is known, and the ultimate production per acre has been estimated, the ultimate production of the well is determined by multiplying the estimated ultimate production per acre by the acres drained by the well. This product should be found on the right margin of figure 5. Then, by following the line representing this product to the left to where it cuts the average ultimate production curve and following the curve downward the first year's daily production is determined. In other words, by using this method one finds that, on an average, a well having a certain ultimate production will have a certain first year's daily production. But the chart gives additional information. By tracing the same line to the left and thence downward from where it intersects the minimum and the maximum ultimate production curves, one can determine theoretically the minimum and maximum daily output that a well on acreage of a certain productivity will yield the first year.

EXAMPLE OF USE OF APPRAISAL CURVES.

Take this example: Suppose the wells, to be on undeveloped lands, will drain an average of 4 acres each when the land is completely drilled, and that the area will ultimately yield 4,000 barrels per acre. The total amount of oil to be produced by each well, therefore, is 16,000 barrels. Follow the 16,000-barrel line from the right margin of figure 5 toward the left to where it intersects the minimum and

the maximum ultimate production curves. The minimum limit thus determined is 13.6 barrels and the maximum is 36.6 barrels daily. In other words, the history of the properties upon which the appraisal curve is based indicates that a well with a daily output during the first year of 13.6 barrels may ultimately produce as much as a well that made daily during the first year 36.6 barrels; this leads to the conclusion that the former well produces under more favorable conditions.

This method gives some idea as to the probable range of initial yearly production, and is preferable to that of determining initial yearly production by the use of composite decline curves. A composite decline curve is based on the average decline of wells of all sizes, and the use of appraisal curves, which show the difference in the ultimate production of wells having different daily productions the first year, obviates the error introduced by averaging the declines of all wells.

To determine initial yearly output is certainly the most difficult problem in estimating the probable annual production of undrilled ground. If one can determine, even within rather wide limits, the amount a well will make during the first year, and if production curves are available that show the yearly decrease in production of a well under similar conditions, the making of the remainder of the estimate is comparatively simple. The approximate depth and, under certain circumstances, the approximate thickness of the sand, and the acreage to be allotted each well are usually known before drilling begins, but nothing as to the probable output of the well during the first year. As has been shown, close estimates of future and ultimate production may be made by plotting the ultimate cumulative percentages of properties against the daily output the first year, thickness of sand, depth of sand, and acreage per well. The limits thus determined are shown in figure 10 (p. 47). With the data given, figure 10 may be used to determine the reasonable limits of the initial yearly production of new wells, and by applying the law of probabilities to these estimates the first year's daily production of a well may be estimated much closer, theoretically, than by using any of the methods outlined above. Although the procedure may be of little practical value in actually estimating future production for the first year, an example is given by way of illustration.

APPLICATION OF METHOD TO UNDRILLED LAND IN CRAWFORD COUNTY FIELD (ILL.).

Suppose one desires to determine the annual rate of production of a well to be drilled on a large tract of undrilled land in the Crawford County field (Ill.). From the geologic data available and the records

of surrounding wells it is fairly certain that the sand lies 400 feet below the surface and is approximately 30 feet thick. It is planned to space the wells so that each will drain approximately 6 acres. What will be the probable daily production the first year of one of the wells?

The conditions affecting the production of the new well are likely to be similar to those in the drilled part of the field, so that by knowing the acreage per well and the depth and thickness of the sand, one will have a fair start in making an accurate estimate of the annual production of new wells on the undrilled tract. The following table shows the statistics obtained from figure 10 in determining the probable future daily production the first year under the specified conditions of acreage, depth, and thickness:

Data obtained from figure 10 in determining probable daily production the first year.

	Limits of ultimate cumulative percentage.		Determined limits of ultimate cumulative percentage.		By applying determined percentage limits—To maximum percentage curve for initial production.		To average percentage curve for initial production.		To minimum percentage curve for initial production.	
	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Bbls.*	*Bbls.*	*Bbls.*	*Bbls.*	*Bbls.*	*Bbls.*
Acres per well, 6	355	200	355							
Depth of well, 400 feet	630	290		290						
Thickness of sand, 30 feet	680	210								
Determined daily production the first year					16	11	9	6	3	1

To determine the limits of the ultimate cumulative percentages as determined by acreage per well, the 6-acre line is followed upward to where it cuts the maximum and minimum percentage lines; then by reading on the left margin the respective values are found to be 355 and 200 per cent. To determine the same percentages for depth the line showing depth is followed downward to the maximum and minimum percentage lines; then readings on the left give 630 and 290 per cent. The maximum and minimum percentages as determined by sand thickness are 680 and 210 per cent. In other words, these are the limitations prescribed by the three different conditions that influence production in Crawford County, Ill.

As shown already (p. 48), the highest minimum percentage, 290, and the lowest maximum percentage, 355, are chosen. To find the most likely maximum daily production for the first year follow from the left margin the lines representing 290 and 355 per cent to where

these lines cut the maximum cumulative percentage curve, and then read upward to the maximum (about 16 barrels) and the minimum (about 11 barrels) daily production. Similar procedure is used to determine the probable variation of wells that follow the average curve or the minimum curve, the same lines being followed toward the right to where they cut the average and the minimum percentage curves. The readings are 9 to 6 barrels daily the first year for the average and 3 to 1 barrels daily for the minimum. The respective limits determined, therefore, are 1 barrel and 16 barrels.

These limits are rather wide, but the chances are much greater that the new daily production will approach the average more nearly than it will the maximum or the minimum lines, and the law of probabilities can be applied to see what the chances are of its falling between 6 and 9 barrels. Obviously, if the probability is 0.5 that the first year's daily production of a new well will be between 6 and 9 barrels and that the chances for its being more or less will decrease with the distance from the 6 and 9 barrel lines, the operator has a definite basis upon which to work. If he knows that there is an even chance that the new well will yield 6 to 9 barrels a day the first year and that there is only a remote possibility of its producing less than 1 barrel or more than 16 barrels, he is in a fairly strong position. With enough data on the yield of different properties, he can apply the law of probabilities and determine the actual probability of the well making a certain initial yearly production. In practice, the wide use of such a method is doubtful because of the variations in the natural and artificial conditions affecting yield and of the lack of data with which to work.

USE OF CURVES SHOWING THE DECREASE IN THE INITIAL YEARLY OUTPUT OF WELLS DRILLED DURING CONSECUTIVE YEARS.

As explained above (p. 51), curves can be drawn to show the decrease in the initial yearly output of wells drilled during consecutive years. Often, if part of a field is uniformly drilled and an estimate of the average initial yearly production of the wells to be drilled in the rest of the field is desired, curves like those in figures 11, 12, and 13 may be prepared and the estimates made from them.

An interesting comparison may be made of the percentage decrease in these curves by designating the amount at the high point on the curve 100 per cent and the amounts during the following years as percentages of that amount. Except in the Kurokawa field (Japan) the percentage decrease in initial production is notably similar, despite the variety of conditions in the different fields.

RELATION BETWEEN INITIAL PRODUCTION OF A WELL THE FIRST 24 HOURS AND ITS DAILY PRODUCTION THE FIRST YEAR.

RELATION IN NEW STRAITSVILLE FIELD, OHIO, AND LAWRENCE COUNTY FIELD, ILL.

Frequently it is important to know the relation between the amount of oil a well yields during the first 24 hours and its average daily production during the first year. The composite decline curves and the appraisal curves prepared are based on the average daily production per well during the first year and often such data for so long a period are not available. Moreover, it is often desirable, after a well has produced a short time, to estimate approximately how much the daily production will be for the first year. Figures 14 and 15 have been prepared to show this relationship.

Figure 14 shows the relation for wells to the Clinton sand in the New Straitsville field, southeastern Ohio, and figure 15 is an example of the relation in the Lawrence County field (Ill.). The close upper and lower limits, shown by the dots (fig. 14), should be noted. The average line was determined by finding the average for the values indicated by the different dots in each vertical area of the chart. Then a smooth curve was drawn through the irregular line drawn from dot to dot. Similar curves can easily be made for any other field.

METHODS OF DETERMINING FUTURE AND ULTIMATE PRODUCTION.

USE OF COMPOSITE DECLINE CURVES.

Composite decline curves show the average decline for wells of different output. Therefore if one of these composite curves is used in figuring the future annual production and the ultimate production of a property whose daily output the first year is considerably below the average, the estimate of future annual production, and consequently of ultimate production, of that property will be less than it should be; whereas if the first year's daily output exceeds that of the average curve the estimates of future annual production and of ultimate production will be considerably higher than they should be.

However, such curves serve a certain purpose, and it was thought wise to give in this form the information collected for the use of those who prefer to use these curves, with their certain error, to other methods.

ESTIMATING THE FUTURE OUTPUT OF UNDRILLED LAND.

In estimating the future production of an undrilled property by means of composite decline curves it has been shown that the most

nportant and difficult problem is that of determining the probble production of each new well for the first year. After the best stimate possible has been made it is a fairly simple matter to deter-

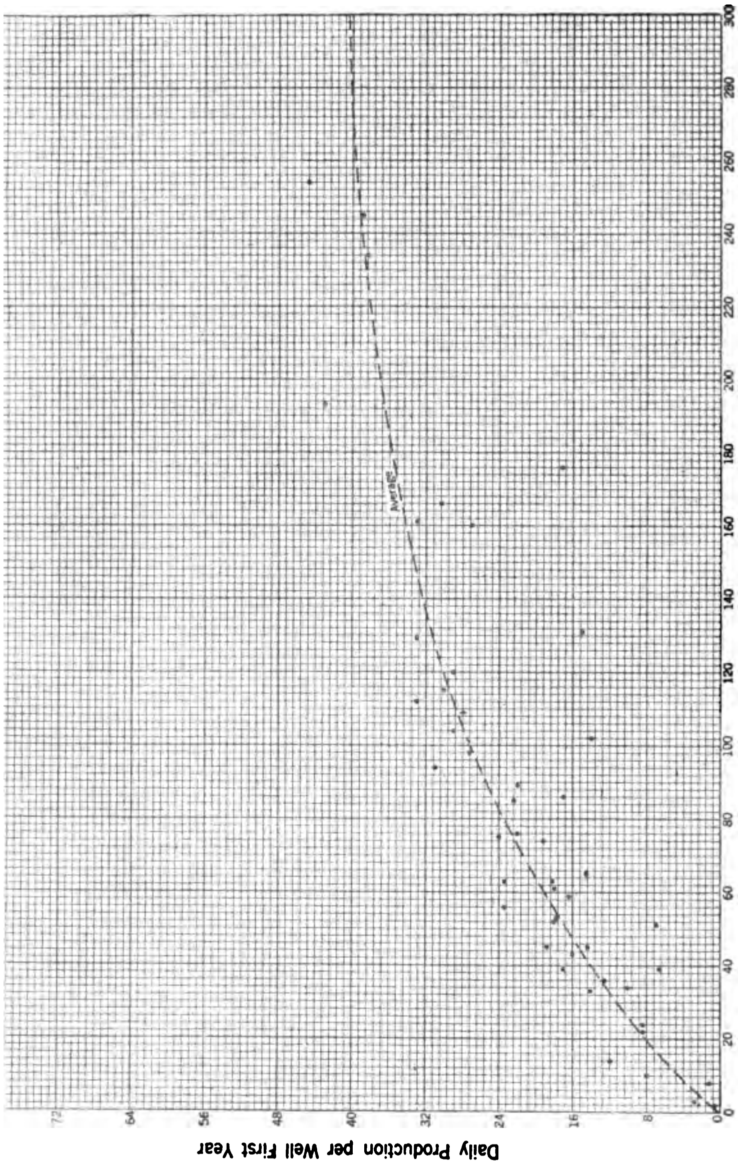

FIGURE 14.—The relation of initial production (first 24 hours) to the average daily production (in barrels) per well the first year in the New Straitsville field, Ohio.

ine the future annual output of the well if a composite decline curve available. For instance, if such a curve shows the percentages for e first two and three years to be 100, 60, and 30 per cent, and 500

barrels is a trustworthy estimate of the average daily production the first year, the annual output of this well for the first three years, if the well is not far above or below the average, will be, successively,

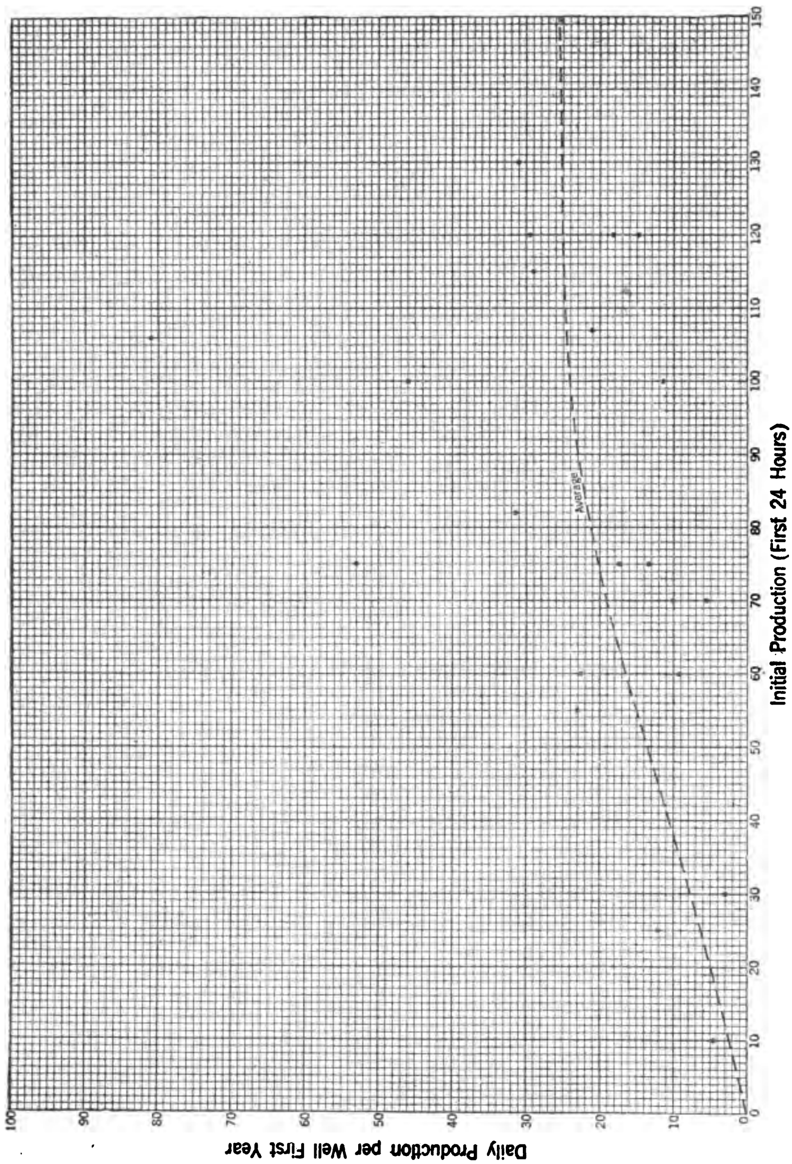

FIGURE 15.—The relation of initial production (first 24 hours) to the average daily production (in barrels) per well the first year in the Lawrence County field, Ill.

182,500, 109,500, and 54,750 barrels. To determine the ultimate production of the well the amounts obtained annually are added; or the yearly percentages can be added to make the ultimate cumulative

percentage, and that can be multiplied by the first year's production. For example, in this instance, if the ultimate cumulative percentage is 300 the ultimate production of that well will be 500 × 365 × 3, or 547,500 barrels. To obtain the ultimate production per acre it is necessary to make some estimate of the acreage drained by the well; on the assumption that this well drains 15 acres, the ultimate production per acre would be about 36,500 barrels.

ESTIMATING THE FUTURE OUTPUT OF PARTLY DRILLED LAND.

When a property is being drilled the operator has not only the data for a composite decline curve, but also the actual past performance of the wells themselves; by these he is able to decrease or increase his estimate of future production according to whether the output follows a curve above or below that of the average well.

DETERMINATION OF THE AVERAGE AGE OF A BARREL OF PRODUCTION.

The method suggested by Washburne[a] for determining the average age of a barrel of production has been used occasionally by the author. It is especially valuable in estimating the future production of several wells of different ages when only a composite decline curve is available. Because of its importance, the salient points and certain modifications of the methods are given here.

Briefly, the method consists of determining the point on the composite decline curve at which the property is producing. For this purpose it is necessary to determine the average age of a barrel of the oil produced. The decline in output of a property that is being drilled is often distorted by the large initial production of new wells. An error would be introduced by using the average age *of the wells* in determining on the typical curve the point occupied by the production of that property, because the wells differ in output. To obtain the average age of a barrel of production on such a lease the daily output of each well is weighted by its age. For the sake of clarity, Washburne's table, with certain modifications, is given below:

Table for determining the average age of a barrel of production.

Well No. 1	Daily production, barrels. 2	Age, months. 3	Product of terms. 4
1	10	18	180
2	12	14	168
3	15	8	120
Total	37		468

[a] Washburne, C. W., The estimation of petroleum reserves: Am. Inst. Min. Eng. Bull. 130, October, 1917, pp. 1866–1868; discussion of paper by R. W. Pack, in Am. Inst. Min. Eng. Bull. 128, August, 1917, pp. 1121–1134.

The average age of the wells is here shown to be 13⅓ months (40 divided by 3), whereas the average age of a barrel of production, determined by dividing the sum of the products (column 4) by the total daily production (column 2), is about 12½ months. Hence to estimate the future production of these wells one finds the point on a curve 12½ months after its beginning. In other words, the 37 barrels of production is the result of a decline for 12½ months of some larger production which, during the first year, is called 100 per cent. If the curve at 12½ months from the beginning reads 60 per cent of what it was 12½ months earlier, then 37 barrels equals 60 per cent of the original production, or about 62 barrels. In other words, if one well made originally 62 barrels daily, 12½ months later it would be making 37 barrels. This method, which has been used with certain modifications by the author and checked against other methods, has decided value under some circumstances. It is based, of course, on the assumption that a composite decline curve showing the yearly production of an average well may be interpreted in terms of months or fractions thereof.

ADVANTAGES OF COMPOSITE DECLINE CURVES.

Composite decline curves have many advantages and the finding of a better method for determining future or ultimate production would be difficult were it not for the basic difficulty of determining the limitations of the estimates made and for the curves representing the average decline of wells of all sizes. One advantage of such curves is that after the average daily production has been determined for the first year the production for any one year can be immediately determined by multiplying the first year's production by the percentage expressed on the decline curve. This can not be done with appraisal curves unless a generalized decline curve, explained on page 64, is used.

LIMITATIONS OF COMPOSITE DECLINE CURVES.

Composite decline curves should not be used in estimating yields in new territory unless the conditions that affect production there are approximately the same as those prevailing in the territory for which the curve has been prepared; in other words, the acreage per well, the operating conditions, the geologic conditions, and the thickness of the sand should be the same. In using a composite curve for estimating yields in a new district some distance from the field for which the curve was prepared considerable inaccuracy must be expected and a large factor of safety allowed for uncertainties of production, differences in geologic conditions, and so forth.

USE OF APPRAISAL CURVES.

As the use of appraisal curves for estimating ultimate and future production for wells already drilled has already been discussed on page 35, examples will not be repeated. The most important advantage in using appraisal curves is that the maximum and minimum limits of the decline of a well may be determined, as well as the same limits for the ultimate production. For determining the limits of the decline of a well, generalized decline curves are of great use.

USE OF GENERALIZED DECLINE CURVES.

Generalized decline curves showing the maximum, average, and minimum rates of decline of wells of any output may be constructed from the appraisal curves, so that one may obtain a ready idea as to the future annual production of a well of a certain size, especially if the well is two or three years old and the trend of its decline is known.

GENERALIZED DECLINE CURVES FOR WELL IN OSAGE NATION.

Generalized decline curves for a large well in the Osage Nation are shown in figure 16. These curves were derived from the appraisal curve of the Osage Nation (fig. 24, p. 107) by computing the decline from the curves of maximum, average, and minimum ultimate production, as explained on pages 41 and 42. Wells with large initial outputs usually follow along or near the minimum curve (fig. 16), whereas wells with small initial outputs usually follow the maximum curve. Production curves of other wells are intermediate, but will fall systematically within the extremes.

PLOTTING THE DECLINE.

To estimate the decline of a well, the daily production the first year may be plotted on the average decline curve at its intersection with the line indicating that production. The ensuing annual productions are then plotted at time intervals of one year each. If the latter points deviate from the average decline curve, the well is not an average well. Thus the plotted decline may approach more nearly the minimum decline curve or the maximum decline curve. Then the first year's output should be plotted on the minimum or maximum curve. Some wells may begin on one curve and then for a few years produce according to one of the other curves, but finally come back to the first curve. However, the actual future of a well can be determined within fairly narrow limits, even though only the first year's output is available.

MANNER OF USING THE CURVES.

The best way to use these curves in estimating the future of a property is to plot the production on a piece of tracing cloth at intervals of one year, using the same vertical scale as that on which the

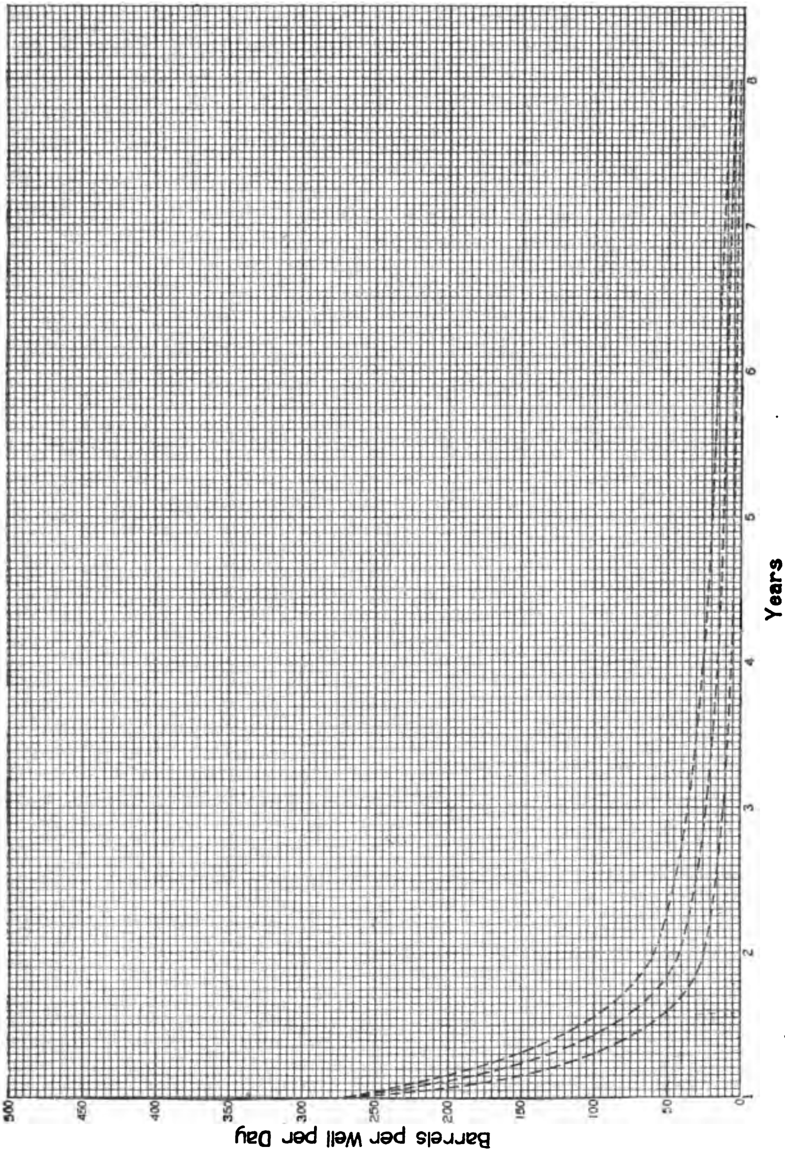

FIGURE 16.—Generalized decline curve of the wells in the eastern part of the Osage Indian Reservation, Okla.

generalized decline curves are plotted. The tracing cloth can then be shifted from right to left to make the production curve fit best one of the three generalized decline curves. The older the well the more

accurate will be the estimate of future production. If a well is only a year old, however, it can be assumed to be an average well and its decline estimated to follow the average curve, with the same probabilities of inaccuracy as in the use of appraisal curves.

It should be noted that the initial yearly production of a well is not always an indication of its decline, for wells of different initial production follow curves of the same type. This is to be expected because different conditions affect the production of different wells. However, as all such variations have determinable causes, it is probable that when more data are available to show the way certain factors influence the output of wells the causes for such deviations from generalized curves can be found and more accurate estimates of future production made.

ADVANTAGES OF THE CURVES.

An operator should construct generalized decline curves of oil properties when he has enough data, for obviously the information thus obtained will be of great value to him. For instance, if individual production records for the wells are available the probable future of every well on a property can be determined approximately by inspecting the generalized decline curve and noting whether or not the decline is above or below the average shown.

In determining ultimate production by use of the appraisal curves, estimates can be made directly from the appraisal curve or generalized decline curves can be constructed for any large well in a field, and the actual production of average wells on different properties can be plotted on the generalized decline curve and the future annual production estimated.

Another advantage of these curves is that the future decline of a well can be readily seen, which is not possible with the appraisal curves. As pointed out later (p. 198) these curves may be used exclusively instead of the appraisal curves.

USE OF APPRAISAL CURVES FOR ESTIMATING FUTURE PRODUCTION OF UNDRILLED PROPERTIES.

Limitations that apply to the use of composite decline curves for estimating the future production of undrilled tracts must also be applied to the use of appraisal curves. All conditions affecting production of undrilled areas should be approximately the same as those for the district for which appraisal curves are available, or the estimator should be sufficiently familiar with the probable influence of the variable conditions.

METHODS OF DETERMINING THE FUTURE PRODUCTION OF FIELDS.

VALUE OF ESTIMATES OF FUTURE PRODUCTION.

Occasionally it is necessary to estimate the future output of an oil field in order to determine the probable amount of recoverable oil not yet produced. Several estimates of this kind have been made for the different fields of the United States, as well as for tracts of land on which production was expected. The sum of the estimates for the fields was taken as the total future production of the United States. The value of such knowledge lies in its giving an approximation of the country's oil resources.

In 1909, Day[a] estimated that the total yield of the petroleum fields of the United States would be not below 10,000,000,000 barrels, and not above 24,500,000,000 barrels. Estimates made in 1916 by members of the United States Geological Survey and the Bureau of Mines, published as a Senate Document,[b] indicated that Day's minimum estimate was more nearly correct than his maximum. In this estimate the ultimate production of the fields of the United States was estimated at about 11,000,000,000 barrels, of which 7,629,000,000 barrels remained to be produced. In general, estimates for large areas if made during early drilling have proved considerably above what the district finally produced. It is impossble to estimate with any degree of certainty the ultimate production of undrilled fields.

METHODS OF MAKING ESTIMATES.

Estimates of the future production of large areas may be made by the same general methods used in estimating the future production of individual tracts; that is, the future yield of the producing wells is estimated, and then the amount that ultimately will be produced per acre is computed. This acreage production is applied to the undrilled area and the ultimate output is estimated.

Another method is to estimate the initial yearly production of the undrilled wells and to find the future annual production by using a composite decline curve applicable to the district.

PLOTTING TOTAL OUTPUT BY TIME PERIODS.

A simple and fairly trustworthy method for estimating the future production of a field, if the output is declining and the field is nearly drilled up, is to plot a curve showing the total output of the field for

[a] Day, D. T., Papers on the Conservation of Mineral Resources: U. S. Geol. Survey Bull. 394, 1909, p. 35.

[b] Gasoline: Letter from the Secretary of the Interior transmitting certain information, in response to a Senate resolution of Jan. 5, 1916, relative to the production, consumption, and price of gasoline. 64th Cong., 1st sess., Senate Doc. 310, 17 pp.

each time period from the beginning of production and to project this curve to the point at which the wells in the field can no longer be operated at a profit. However, if the output of the field is not declining, some other method must be used.

PLOTTING DAILY PRODUCTION PER WELL.

Another simple method, one more nearly accurate than the preceding, is to plot the curve showing the production per well per day for any time period. By projecting this curve the average production per well per day can be estimated for any period. This method has not been used as much as it should be, because some persons believe that inasmuch as all the wells in the field have not been drilled the daily production per well will be upheld by the yield of new wells. This objection is not valid, especially if the production per well in a district has begun to decline on account of interference. After a field has attained a certain age the rate of decline in the daily production per well remains practically unchanged, regardless of the number of new wells drilled. Essentially, the reasons for the rate not changing are that the initial production of the new wells drilled is reduced by interference of older wells, and the actual number of new wells is so small a proportion of the total number of wells producing that the output of the new wells is correspondingly insignificant. Hence, the daily production or the monthly or yearly production, per well after a field has attained maturity and interference is fairly prevalent throughout, may be used in estimating future production without fear that the new wells drilled will materially change the rate of decline of the average well. It is necessary that the wells shall be drilled close enough to be affected by drainage. In a field where the productive sand is lenticular, or made up of several disconnected lenses, or if the wells are being widely spaced the statement will not always hold.

This method has often been used by the author in determining the normal decline of a field, in finding the number of wells to be drilled in an area to maintain or increase production, or in estimating the future production of the area. It is easy to apply and is sound in principle, as it is based entirely on the past performance of the wells. Several years ago McLaughlin[a] mentioned the possibility of using the method.

DETERMINATION OF NORMAL DECLINE OF MIDWAY-SUNSET FIELD, CAL.

To determine the normal decline of the field for any period the time when a constant number of wells were producing is selected, and the decline for the whole group from the beginning to the end

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[a] McLaughlin, R. P., Petroleum industry of California: California State Mining Bureau, Bull. 69, 1914, pp. 57–58.

of the period is determined. Figure 17 shows the curves used for this purpose in the Midway-Sunset field (Cal.). Here the production has declined to 40 to 50 barrels daily per well, and the influence

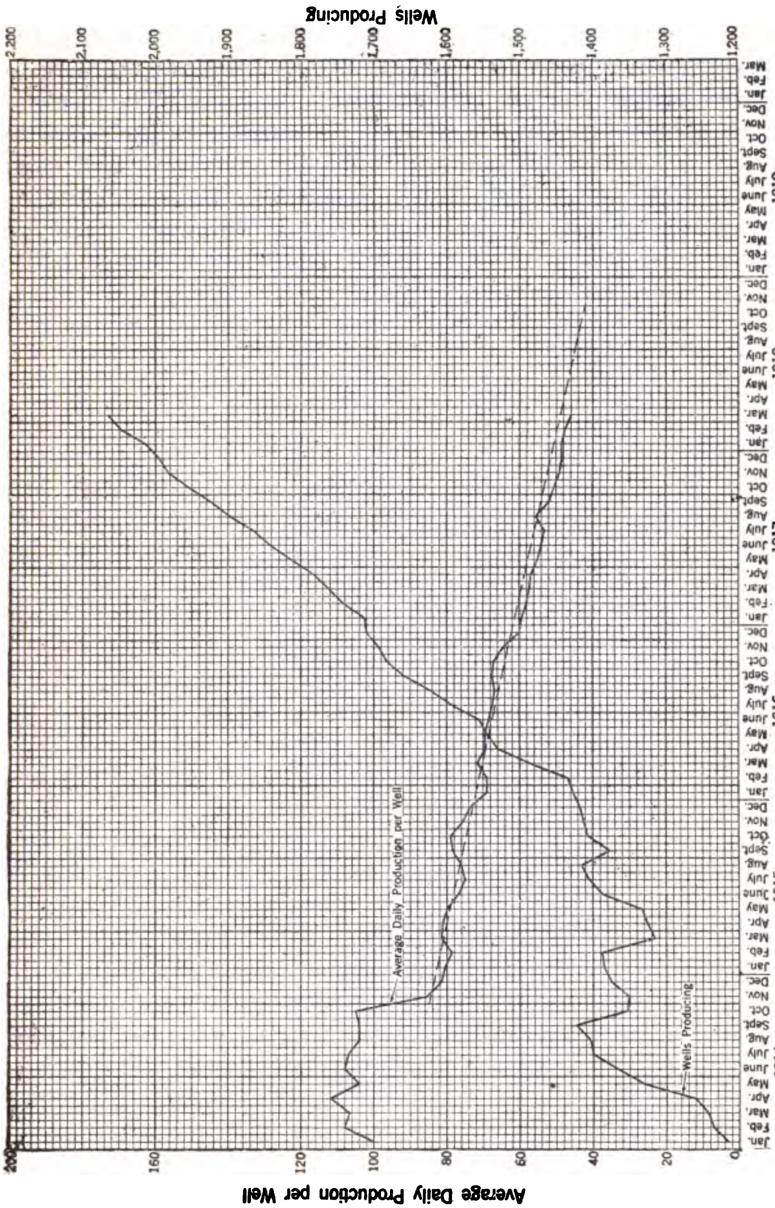

FIGURE 17.—Chart showing the method that may be used to determine the normal decline of the Midway-Sunset field, Cal., the number of new wells to be drilled to maintain or increase production, and the future production of the field. Figures for average daily production are in barrels.

of new wells is not as noticeable as in the early history of the field. The curve showing the daily production per well declines regularly for several years and can be projected into the future with small

error. In this way the percentage decline for any period can be computed.

Although such a selection really was unnecessary, as the influence of new wells was negligible, a period was selected when little drilling was done. For instance, the daily production per well was 85.5 during November, 1914, and 71.5 barrels during February, 1916, a decline of 14.0 barrels daily, or 16.4 per cent in 1¼ years. The resulting average is about 13 per cent a year. This estimate was checked by taking the period from January, 1916, to January, 1918, and using the average line instead of the actual production figures. The computed decline was about 16 per cent. The two estimates are in fair accordance regardless of the fact that nearly 600 wells were drilled during the latter period and only 85 during the former. So that 15 per cent was taken as the normal decline in the Midway-Sunset field for the coming year.

DETERMINATION OF NUMBER OF NEW WELLS NEEDED TO MAINTAIN OUTPUT.

To determine the number of new wells to be drilled to maintain the production for March, 1918, to March, 1919, the following procedure was adopted: The daily production per well during March, 1918, was 46 barrels. By applying the normal decline of 15 per cent one finds that the daily production during March, 1919, would be 39 barrels per well. The daily production of the field during March, 1918, was 95,334 barrels, and if this production is to be maintained, the number of wells that must be producing during March, 1919, is determined by dividing 95,334 by 39, which gives 2,440. As the number of wells producing March, 1918, was 2,065, 375 wells (2,440–2,065) must be drilled during the year between March, 1918, and March, 1919.

Suppose it was desired to increase the daily production of the field to 120,000 barrels daily during the ensuing year. The number of wells that must be producing in March, 1919, is determined by dividing 120,000 by 39. The quotient is 3,075. Subtracting 2,065—the number of wells producing in March, 1918—leaves 1,010 wells as the number to be drilled. This procedure not only affords a quick and trustworthy method of estimating the number of wells to be drilled to carry out any production program, but also shows what a large number of wells must be drilled in a field of that size to increase materially the daily production.

ESTIMATING FUTURE OUTPUT OF A FIELD.

To estimate the future output of the field requires only the determining of the number of wells that remain to be drilled, the plotting of these in a curve showing the rate at which they are to be drilled, the projecting of the curve showing the decline in the average daily

output per well to a point at which the wells can not be economically operated, and then determining the total production for each month by multiplying the daily output per well by the days in a month and this product by the number of wells producing. The future output may be obtained by addition.

Some persons may think that this method is fundamentally wrong because it takes no account of the flush production of new wells. But in a field several years old the new wells have little influence on the average production per well a day, and drilling may be practically ignored. This generalization holds true in the other California fields, and unquestionably is true in the oil pools of the Mid-Continent district, where the sands are not as thick, interference between the wells is more rapid, and the wells decline more quickly.

ESTIMATED NORMAL DECLINE OF OTHER CALIFORNIA FIELDS.

By use of this method the author has determined the normal decline of other California fields, as follows: McKittrick, 9 per cent; Kern River, 8 per cent; Lost Hills-Belridge, 10 per cent; Coalinga, 10 per cent; and Lompoc-Santa Maria, 10 per cent. The normal decline for all of California was also determined, by combining the results of the individual fields, as between 11 and 12 per cent. The percentages of new wells required to maintain production as determined in this manner coincides rather closely with Lombardi's[a] estimates. For instance, Lombardi gave for the Coalinga field, 9.33 per cent, and for the Midway-Sunset field, 14.8 per cent of new wells, whereas the respective percentages, by using the method above, are 10.9 and about 18 per cent. For the whole State the author estimates that about 11 per cent more wells must be drilled during the next year to maintain production, whereas Lombardi estimated the increase as 8.22 per cent.

Pack[b] gives a modification of the method; by this the future production of a field at different times can be estimated. Most of the methods evolved were based on the maintenance of production and on the number of wells drilled during the periods in which production was maintained or was declining at a known rate.

ESTIMATING FUTURE OUTPUT BY DETERMINING AVERAGE AGE OF PRODUCTION.

As explained on page 62, a feasible method of estimating the future production of wells already drilled in a field is to determine

[a] Lombardi, M. E., The cost of maintaining production in California oil field: Am. Inst. Min. Eng., Bull. No. 105, September, 1915, pp. 2109–2114.

[b] Pack, R. W., The estimation of petroleum reserves: Am. Inst. Min. Eng., Bull. 128, August, 1917, pp. 1121–1134.

the average age of production. The only information required is: (1) a composite decline curve of several wells or properties in the field; (2) the present daily production of the wells for which the estimate is to be made; and (3) the total amount of oil already produced. The object is to determine the point on the composite decline curve at which the average barrel of production is declining at present—in other words, to determine the average age of a barrel of production. The total daily output for all the wells can then be considered as the actual output for one day for one great well of a certain age. With this age determined, the first year's daily production of this well may be found by dividing its present daily output by the percentage, on the decline curve, indicated by the age of the production. After this has been found the actual output in future may be obtained by applying the curve values for the future years to the first year's daily production. As the method has already been fully explained (p. 62), it is not discussed in detail here.

ESTIMATING BY USE OF APPRAISAL CURVE.

An appraisal curve, if it is available, may also be used for estimating the future or ultimate output of the producing wells in a field, the average production per well for the field being determined and the future or ultimate production of a well of that output being estimated. Then the future production of this average well should be multiplied by the number of wells in the field.

ESTIMATING BY "SATURATION METHOD."

If a field has just been discovered and little information is to be had on the probable action of the wells drilled, a possible way of estimating its future production is by the "saturation method." As an example of the application of this method during the early history of a field, the estimate made by Shaw as to the quantity of oil in the Carlyle field (Ill.) may be cited. Shaw says[a] that this estimate was made five months after the field was discovered and that it was proving better than estimates that could have been made by any other known method. As a general rule, however, estimates by this method should be made only after careful consideration of all available data and then only with the object of determining within wide limits the field's probable future production. Obviously, the unknown factors entering into an estimate of this kind are too many

[a] Shaw, E. W., Discussion of paper by A. W. Lauer on the Petrology of reservoir rocks and its influence on the accumulation of petroleum. Econ. Geol., vol. 13, No. 3, May, 1918, p. 214.

for the accurate determination of future output and the accuracy of successful estimates made by the method is due probably to the compensating error introduced by guessing at many unknown factors. For instance, no one can say for a certainty what percentage of the total oil stored in the rocks will be recovered. Furthermore, practically nothing is known as to the pore space in the reservoir, and information on the extent and thickness of the reservoir must be inferred almost entirely from geologic observation. Even though it were possible to determine closely, after the first well had been drilled, the total amount of oil in a field there still would be great chance of error in estimating the recovery factor.

OTHER POSSIBLE METHODS OF DETERMINING FUTURE PRODUCTION.

USE OF RECORDS OF COMPOSITION AND VOLUME OF GAS.

Profitable investigations on estimating future oil production can undoubtedly be made by studying the changes in the composition of the gases accompanying the oil as a well becomes older. The author has done no work of this kind, and owes the suggestion to Mr. J. O. Lewis, of the Bureau of Mines. More data should also be obtained as to the cubic feet of gas accompanying each barrel of oil produced for different periods of the life of a well. Everyone familiar with the drilling of oil fields knows that a well usually gives most gas when it begins producing. From that time onward, under normal conditions, the quantity of gas per barrel of oil produced constantly decreases; moreover, the composition of the gas changes. Hence, these two possibilities should be studied together. Very likely if oil producers noted the average quantity of gas accompanying each barrel of oil from their wells during each month, the data could be compiled so as to yield inferences of much interest, for it is believed that the decrease in the volume of gas accompanying each barrel of oil throughout any period corresponds closely to the decline in the output of oil. To collect this information in the oil fields of the United States is difficult, for, so far as the author knows, not many records of the gas that accompanies the oil are kept.

There seems much promise of obtaining profitable and interesting results by comparing the decline of well pressures with the decline of oil production, for the output of a well, especially during its flowing life, is beyond doubt closely related to the force that causes the well to flow. Moreover, it is fairly simple to ascertain and record the pressure in the well during its flowing life. Figures 18, 19, and 20

are excellent examples of the relation between the decline of well pressure and that of oil production. The reader should note how closely the curves showing well pressure and oil production correspond. Thus, in figure 20, after the month of November, 1914, the curve representing the well pressure seldom fluctuates without there being a noticeable similar fluctuation in the curve showing the average daily output of the well. For example, during January, 1915, there is a depression in the curve showing the pressure of the well. The production curve shows a similar depression. During

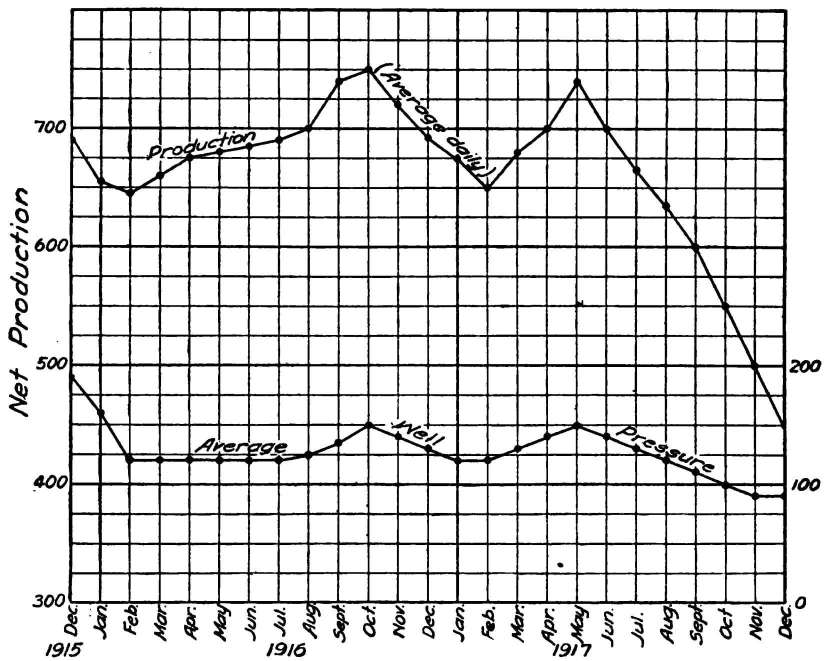

FIGURE 18.—Chart showing the decline in rock pressure (in pounds per square inch) and the corresponding decline in oil production (in barrels) of a well in the Midway field, Cal.

the next month the pressure went up and the production correspondingly increased. For the next two months the pressure was reduced somewhat and the production dropped off rapidly. From May, 1915, both production and pressure decreased rapidly to June, 1916, when the production increased a trifle, and during July, 1916—a month later—the pressure became greater. The increase of pressure and production continued until October, 1916, when both declined. The curve showing the increase in water should be noted also.

Some of the more progressive companies in the different fields of the United States are now taking similar observations, and it is

hoped that enough data will soon be available to prove or disprove the value of such a method of estimating future production. One

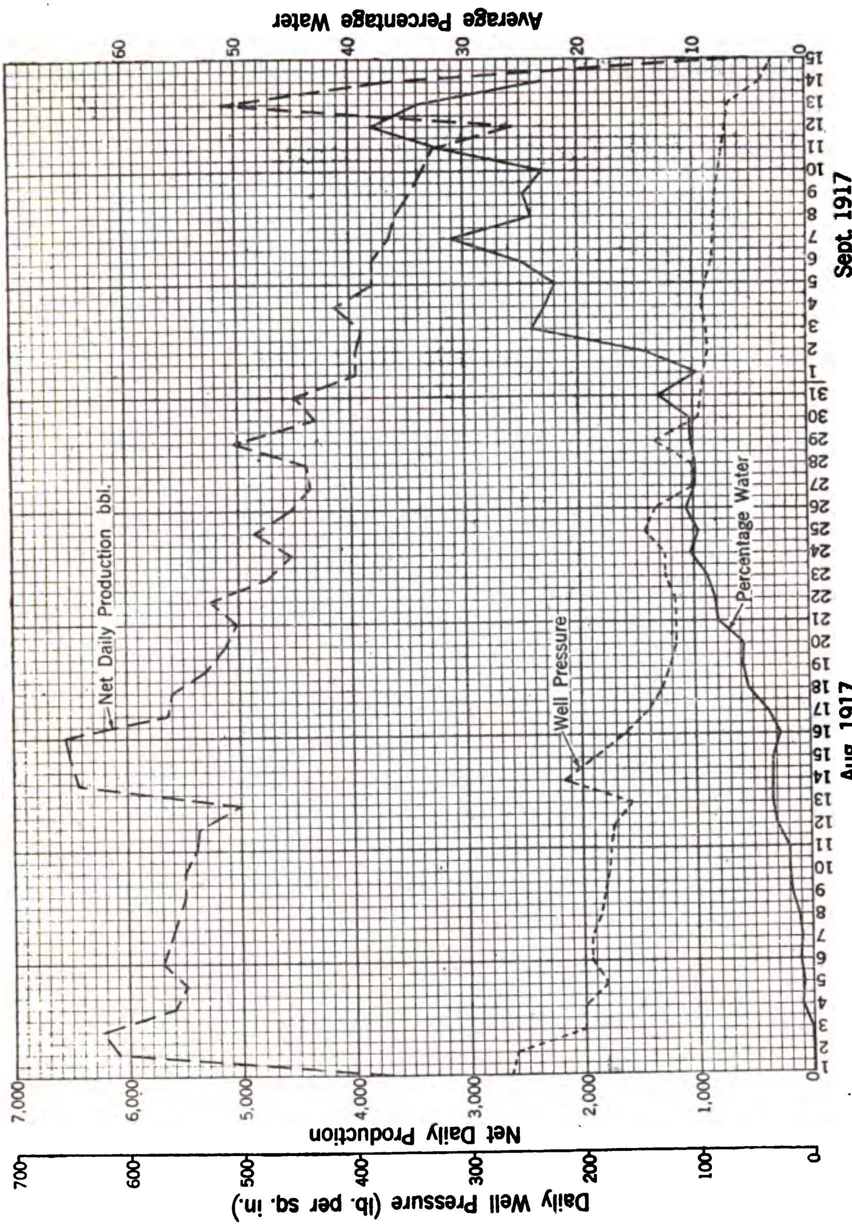

FIGURE 19.—Chart showing the relation of rock pressure to oil production of a well in the Midway field, Cal.

of the disadvantages is the difficulty in ascertaining the well pressure in pumping wells.

MAKING HASTY ESTIMATES OF THE FUTURE PRODUCTION OF OIL WELLS.

In valuing drilled oil lands the appraiser often finds he has to make hasty estimates of the approximate future production of a property, though he may have few data at hand. Hence it is neces-

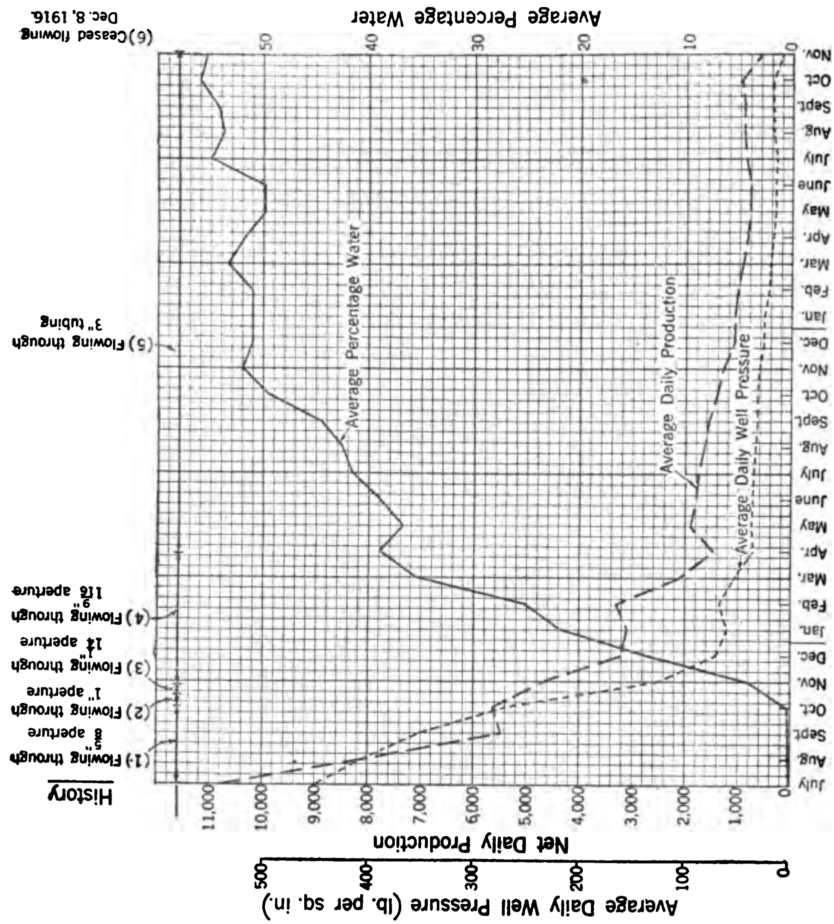

FIGURE 20.—Chart showing the decline in rock pressure and the corresponding decline in oil production and increase in water in a well in the Midway field, Cal.

sary for him to have much general information on the probable action of oil properties under certain conditions, and, in addition, several rule-of-thumb methods that enable him, on short notice, to estimate roughly the future output under certain conditions. Although these methods may not insure exact results, nevertheless they afford a general idea of the probable worth of a property as shown by a rough determination of its future output.

DATA USUALLY AVAILABLE FOR ESTIMATES.

About the only data immediately available, when estimates are required on short notice, are as follows: (1) The past production of the property; (2) the approximate age of production, especially if the property has been completely drilled at approximately the same time; (3) the present daily production per well; and, occasionally, (4) the output of the property during the first year, or the average daily production per well during that period. If considerable information can be collected the appraisal curve may be used, especially in making a rather detailed estimate of the future production. Otherwise, for rapid calculations, figure 21, which for the lack of a better name has been called an estimating chart, will prove useful.

USE OF ESTIMATING CHART.

BASIS OF CHART.

Briefly, this chart is based on the annual ratio of the future to the past production of wells of various sizes the first year, and has been computed from the appraisal curve. For example, if the annual production of a 10-barrel well on a property in the Crawford County field (Ill.) is known, the future production at the end of each year can be calculated in accordance with the following table:

Relation of past production to estimated future production.

Years. 1	Estimated annual production, barrels. 2	Total past production at end of year, barrels. 3	Estimated future production at end of year, barrels. 4	Ratio between future and past production, cols. 3 and 4. 5
1	3,650	3,650	6,450	1.77
2	1,680	5,330	4,770	.89
3	1,000	6,330	3,770	.60
4	730	7,060	3,040	.43
5	650	7,710	2,390	.31
6	390	8,100	2,000	.25
7	320	8,420	1,680	.20
8	280	8,700	1,400	.16
9	230	8,930	1,170	.13

CONSTRUCTION OF CHART.

In the table above the average ultimate production for a 10-barrel well in the Crawford County field is 10,100 barrels. After the well has produced one year at the rate of 10 barrels daily, its estimated future yield will be 6,450 barrels. The remainder of the table is computed in the same manner. Thus at the end of the first year there is an estimated future production of 6,450 barrels, and the well

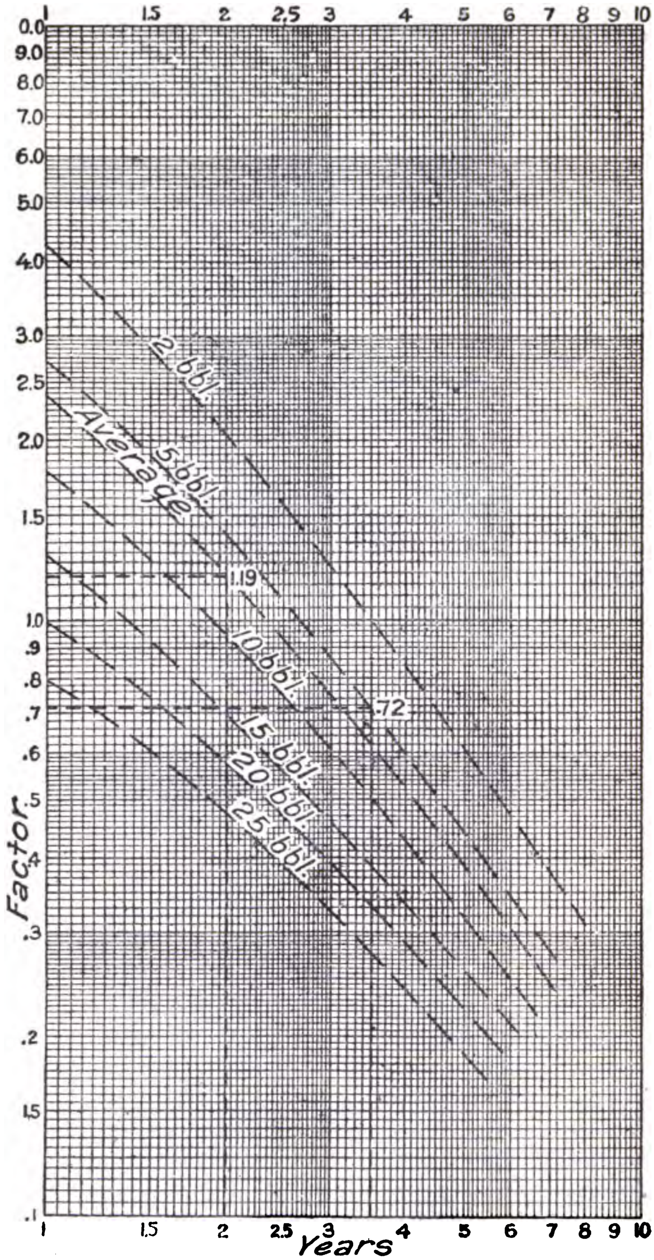

Figure 21.—Estimating chart for roughly calculating the future production of wells in the Crawford County and Clark County fields, Ill.

has produced 3,650 barrels, which gives a ratio of 1.77. In other words, with the past production given—3,650 barrels—the future can be determined by multiplying it by the "factor," or ratio, of 1.77. The ratios are then plotted on logarithmic coordinate paper against the ages of the well during successive years. This paper was used because, as has been said, the curves plotted on it more nearly approach straight lines. It will be noted that the same method of procedure as was used in determining the curve for the 10-barrel well was also used for determining curves for wells of other sizes and also for the average well. The last curve was computed so that if it would be impossible for the appraiser to determine the average daily production per well on a property during the first year, he could use the average curve with the same chance of error as is involved in the use of composite decline curves instead of appraisal curves for estimating future production.

MANNER OF USING CHART.

With such a chart available, if the appraiser can determine the average age of the production, and if he knows the average past production per well, the future output can be found by simple multiplication. For example, the production on a property in the Crawford County field is 3½ years old (fig. 21). The average past production per well is 4,000 barrels. Assume that the average daily production the first year was 5 barrels, then the average future production per well is determined by following the 3½-year line vertically to where it intersects the 5-barrel line, following thence horizontally to the left margin, and reading the factor, 0.72. The past production—4,000 barrels—multiplied by 0.72 gives the average future production for each well, or approximately 2,900 barrels.

If the average daily production the first year is not known the best method of procedure when only the average past production per well and the age are given, is to use the average curve. For example, assume the age is 2 years (fig. 21). The average well has produced 6,000 barrels. The average future production of each well is determined by following the 2-year line vertically to its intersection with the average line and thence to the left margin where the reading found is 1.19. The average past production, 6,000 barrels, multiplied by 1.19 gives the average future production per well, or 7,150 barrels.

One point that should be brought out is the compensating error introduced by the action of properties that are better or worse than the average. The curves in figure 21 are based on the average well. Now the output per well on a certain property may have been much above

the average, so that multiplying the past production by the factor or ratio would make the estimate of future production too high. However, estimates of the future production of such wells have disproved this conclusion, for the future production of the better properties is higher than that of the average properties. The ratio between future and past production is, therefore, approximately the same, and practically no error is introduced by using the chart for estimating the future output of properties above or below the average in productiveness.

If a property is not completely drilled, the future production obtained by the method just given can be added to the past production and the ultimate production per acre of the drilled area can be determined. These values may be applied, with proper modification, to the undrilled proved acreage to determine its approximate ultimate production.

VALUE OF ESTIMATING CHARTS.

These charts for roughly estimating future output should not be used except where hasty estimates are to be made, for they represent the action of average wells of the indicated daily production for the first year, and do not show, as do the appraisal curves, the maximum and minimum limits, so that if enough time is available and the necessary information at hand, much closer estimates of ultimate and future production may be obtained by the use of appraisal curves and from the generalized decline curves. Moreover, the rate at which the oil is to be obtained may be computed.

Part 2 contains estimating charts for some of the fields of the United States, and although they may have little value except in exceptional cases, yet if used with due regard to their limitations, they may save considerable work in obtaining rough estimates of ultimate and future production.

NOTES ON THE VALUATION OF OIL LANDS.

GENERAL CONSIDERATIONS.

The valuation of oil properties demands much more than the mere determination of the possible yield of a property, although this and the rate at which the oil is to be obtained are the chief factors in making valuations.

No set rule can be laid down for determining future and ultimate production, because the procedure to be followed depends primarily on the character of the valuation required and the number and character of the properties to be valued. For instance, an approximate value may be desired of several hundred properties or a pains-

taking estimate of one property. The methods of making these two valuations are radically different. In making the first the appraiser, on account of the labor involved in determining even a rough value of several hundred properties, must adopt methods of shortening the time and of minimizing the labor. The variations in the manner of applying the methods given are many and the checking of estimates made by two or more different methods is always desirable.

CLASSIFICATION OF PROPERTIES TO BE VALUED.

Regardless of the accuracy of the estimates to be made, the appraiser is confronted at the start by the kinds of properties to be valued. These may be divided roughly into three different classes: (1) Properties practically all drilled; (2) properties partly drilled and on which more drilling is to be done, and (3) properties on which no drilling has been done.

In determining the value of properties that are practically all drilled, the most important task necessarily is to determine the future output of the drilled wells and the rate at which the oil is to be obtained. The drilled area of a partly developed property may be treated in the same way; but for the undrilled areas of the partly developed properties and for the undrilled properties, a different procedure must be followed. These undrilled tracts must be classified according to their probable productiveness, a drilling program must be postulated, and the future annual production then determined.

CLASSIFICATION OF UNDRILLED LAND.

The classification of undrilled tracts according to their probable productiveness is necessarily based on geologic inferences that may be more or less uncertain, so that the whole valuation becomes just that much more liable to error. Geology is not a mathematical science; it can be applied to oil-land valuations only in so far as it aids the making of an estimate that in itself is usually an approximation.

Undrilled acreage should be divided, if possible, into (1) proved oil land, (2) probable oil land, (3) prospective oil land, and (4) worthless territory, so far as the economical recovery of oil is concerned. Occasionally much more detailed classifications are made, but the writer believes this refinement incompatible with the uncertainty as to underground conditions.

The classification is given not as something that geologists engaged in oil-land valuation should adopt but as a suggested method of ascertaining the probable value of undrilled land. The boun-

daries between the different classes of land can not be easily determined, and no set rule can be made for any classification, as, in the final analysis, the segregation rests practically altogether on personal opinion, molded by the balancing of all available evidence.

PROVED OIL LAND.

The first class should include those areas in which drilling involves practically no risk. Just what constitutes proved oil land depends, it is true, upon local conditions. All of some quarter sections on which only one well has been drilled may be called proved oil land, even though it may not be surrounded by wells. Other tracts, on the contrary, before they could be considered proved, would require many tests; in drilling such land "every well is a wild-cat well," to use an oil-field saying.

The following definition of proved oil land has been modified from that given by the California State Mining Bureau [a]: "*Proved oil land* is that which has been shown by finished wells, supplemented by geologic data, to be such that other wells drilled thereon are practically certain to be commercial producers."

PROBABLE OIL LAND.

Probable oil land, as the name implies, includes those areas where from geologic inferences as to the structure and the continuity of the sands, and from the information obtained by drilling, the chances favor the finding of oil, although considerable uncertainty may attach to drilling on such land.

PROSPECTIVE OIL LAND.

Prospective oil lands include those areas, classified entirely by geologic observations, on which all available evidence indicates the possible presence of oil in commercial quantities.

WORTHLESS LAND.

Worthless territory is that which has been proved nonoil bearing by drilling, or that in which from geologic observations, the chance of obtaining a profitable yield of oil is remote. All land containing oil that can not be recovered with profit must also necessarily be placed in this class; hence, an area that may be rated worthless at the present time may become, with higher prices for oil or the development of more economical processes, proved oil land in the future. Similarly the drilling of one well on what is now prospective oil land may place the land in the probable or proved class.

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[a] McLaughlin, R. P., Petroleum Industry of California: Cal. State Min. Bureau, Bull. 69, 1914, p. 69.

NEED OF ESTIMATING INITIAL YEARLY PRODUCTION.

In estimating the annual production of undrilled land, it is necessary to estimate the future initial yearly production of the wells to be drilled or to make estimates of the probable production per acre of the tracts of land in the different classes, so that composite decline or appraisal curves may be used to determine the future production for each year. Often it is a good plan in making such ultimate-production estimates to call the ultimate production of the proved oil land 100 per cent and to estimate the probable productiveness of the tracts in the remaining classes by assigning a factor to each class. For instance, probable oil land may be considered 75 per cent as valuable as proved land, and so on. The percentages assigned each class are necessarily arbtirary, as they depend on local conditions and on the judgment of the person making the estimate.

IMPORTANCE OF PROSPECTIVE RATE OF DRILLING.

A matter of primary importance in oil-property valuation is the rate at which the oil may be expected, or the future annual production. For properties not fully drilled, this production depends on the rate of development or the yearly drilling program; no accurate valuation of oil land can be made, nor should it be attempted, without considering this program. Usually the company desiring the valuation has a fair idea as to the rate at which the property is to be drilled. If such knowledge is not available the engineer should assume a drilling program that in his opinion will insure the most economical development of the property.

Estimates must be made of the probable future annual production of each property so that one may determine: (1) Future annual net income (apparent value), and (2) the present value of these deferred net receipts (actual value). The actual present value of a tract is the sum of the present value of the future net annual receipts. The present value of an income that is to be available, for example, 10 years hence, is the sum that when invested at an accumulative rate of interest, compounded for 10 years, will equal the income. "Accumulative rate of interest" is here defined as the rate of interest on capital on a practically secure investment, as distinguished from the "remunerative rate of interest," which is the rate the investor seeks when his capital is to be put in an uncertain venture.

RELATION OF PRESENT VALUE TO DEFERRED PROFITS.

To understand more clearly the application of present value to deferred profits one must consider that when an oil property is bought the purchase price is taken from where it may earn interest and

invested in oil that brings no returns until recovered and sold. Thus there is a loss of interest pending the recovery and sale of the oil. Where oil deposits are relatively certain investments and the future annual production, and hence the annual net profit, can be estimated, the present value factor should be applied to the deferred profits. Occasionally, however, the investment is rendered so speculative by uncertainty as to the presence of oil in commercial quantities that the added refinement of discounting deferred profits is not warranted. Furthermore, the uncertainty of the future price of oil may not justify such refinement.

The annual net receipts for the future are controlled by (1) the future annual production; (2) the future cost of development; (3) the future cost of production; (4) the future price of oil; (5) the rate of amortization of capital; and (6) the salvage value of the equipment. Thus, to compute the value of an oil property, one must determine the present value of the deferred or anticipated profits, which will be the equivalent of a remunerative interest on the capital invested. The rate of interest demanded depends on the risk of the investment, and the return, or the amortization, of the capital invested, depends on the hazard of the investment and the probable life of the property.

To determine the influence of the different factors on annual net receipts is sometimes very difficult. For instance, although one may determine, with what is believed to be considerable accuracy, the future annual output of a property he may find great difficulty in predicting the price of oil, although that of course controls the annual net receipts. The future cost of development and of producing oil should give little trouble to the appraiser who has at hand data on the past cost of development and production.

Not only the interest demanded on the investment but the capital itself must be returned to the investor before the property is abandoned. This redemption of capital is necessarily based on the life of the field, but as the life of most oil properties is uncertain the time in which the invested capital is written off is in general considerably less than the probable actual life of the field.

After a field has been depleted so that pumping is no longer profitable, some of the equipment may be sold for a certain percentage of its original cost. This asset, however, is usually a very small factor in the actual value of the property, inasmuch as many properties have a life of 20 to 30 years and the material actually used in pumping to exhaustion has little salvage or scrap value. The usually small value of scrap at the time the lease is abandoned is further reduced by the necessity of computing its present value, as this sum, like the net receipts from the property during any year of

productive life, is a deferred or anticipated return. Furthermore, the cost of abandoning a property is often greater than the value of the "junk."

METHODS OF PURCHASING OIL LANDS.

There are two general ways of purchasing oil lands. The first is by what is known as the "settled-production" method. In this a certain unit value per barrel of daily production, exclusive of the royalty, is given, this value being based on the gage of the output of a property for several days. The second method is by actually appraising a property, or, in other words, by determining the amount of money that the purchaser can afford to invest in the property under certain conditions.

"SETTLED-PRODUCTION" METHOD.

BASIS OF METHOD.

The first, or "settled-production" method of buying producing-oil properties is the one in common use east of the Rocky Mountains. This method was probably evolved for the dual purpose of rapidly valuing properties and of determining depletion for writing off the capital invested; at any rate it originated in the Appalachian region, where some rapid method of determining the relative value of different properties was necessary. The method is based upon the "settled production" of a well or property, the output of the property being gaged for several days to determine the actual daily yield. Then the royalty interest and the pipe-line deduction of 2 or 3 per cent (common in most of the fields east of the Rocky Mountains and made on account of the presence of sediment and water in the stock tanks) are subtracted from the daily output. A unit value per barrel is paid for the remainder of the daily production, or the working interest.

For example, if the daily output of a property as determined by a several days' gage is 100 barrels, the pipe-line deduction of 3 per cent leaves 97 barrels and the deduction of the royalty interest of 12½ per cent from this leaves a working interest of 84.9 barrels daily. The value of a barrel of daily output depends on the number and value of the undrilled wells, on what percentage of the daily output is "flush" production—that only a few weeks or months old—on the present and the probable future price of oil, on operating costs, and on the productivity of the present wells. In the example given, if the value per barrel is $1,000, the value of the whole lease is $84,900.

An attempt has been made to discover what is the basis for determining the value of a property by this method. On what does the purchaser rest his estimate? Has it any scientific foundation or is it

a mere guess? A method so widely used must be based on some easily ascertained condition that makes it of value and applicable in so many different districts and properties. It was found that the method probably has no scientific basis.

With a knowledge of the factors controlling the value of a barrel of production, the usual buyer proceeds much as he would in buying a horse, the value depending not so much upon the profit he can derive as upon the market value of the horse. This value—which is not the price of oil—seems to be the average of the opinions of the operators dealing in oil lands, the opinion of each operator being determined by the " feel " of conditions, and not, except for a few men, by actually computing the difference between probable total expenditure and probable gross income. This explanation does not signify that operators who employ this method in purchasing oil lands proceed blindly; the opposite is true.

In some districts an increase of 10 cents in the price paid the producer for oil arbitrarily increases the unit value per barrel of the oil by $100. For instance, if the settled daily production of a certain property is worth $1,000 per barrel with oil selling at $2.50, an increase in the price of oil to $2.60 would increase the unit value to $1,100 per barrel. This graded increase may not hold at the present time.

RETURN OF PURCHASE PRICE.

Frequently the purchaser demands that his money be returned within three years from date of purchase. For instance, one operator in Oklahoma expects 45 to 50 per cent of the invested capital returned the first year after he purchases the property, 30 per cent during the second year, and 20 to 25 per cent during the third year. The return of the purchase price may be expected from the production of the old wells, which of course are declining, or from the production of the wells to be drilled. The author believes that the demand for the return of invested capital in such a short time as three years is ultraconservative, except where the future yield of properties is highly uncertain.

INCOME OF PROPERTIES BOUGHT ON " SETTLED PRODUCTION " BASIS.

In studying this method of oil-land valuation the author collected data on the income derived by several companies from many properties purchased by the " settled production " method. The age and amount of the settled production when a property was purchased and the number of wells producing at that date were determined. Next the total investment was computed from the unit price paid per barrel, and the properties were classified according to the royalty paid,

whether or not drilling was done after the purchase. Then all the different classes of properties were compared.

A most interesting table was prepared and comparisons made as to the length of time required for the properties on which new wells were drilled and for those on which no new wells were drilled to repay original cost. Such statistics have no great value, as conditions for different properties vary, and an increase in the amount received per barrel by the producer during a few months of the prolific part of a well's life will materially increase his net income and cause the property to "pay out" so much the sooner; but some of the conclusions obtained by studying one group of properties are given below because of their possible interest to the reader.

For instance, in Illinois, of 88 properties that changed hands in Clark, Crawford, and Lawrence Counties, at an average price of about $375 per barrel of settled production, 50 of the properties, or 57 per cent, "paid out" within 4 years and 10 months. At the time the information was collected—an average of about 6 years after the properties were purchased—the remaining 43 per cent were still in debt. On 39 of these properties no new wells were drilled after the date of purchase; and 19 of these 39 properties, or 49 per cent, "paid out" in the same length of time as the others—4 years 10 months. New wells were drilled on 47 properties, of which 61 per cent "paid out" in the same length of time—4 years 10 months.

The properties were also classified according to the age of the production when the purchase was made. Those having a production less than 2 years old (1) were separated from those with production more than 2 years old (2). Likewise, the properties in each of these two groups were separated into two classes, (*a*) those on which no drilling was done after the date of purchase, and (*b*) those on which new wells had been drilled. The results of this classification and the conclusions obtained are shown in Table 2.

Sixty-eight per cent of those properties in group 1, class *a* (production more than 2 years old at the date of purchase and no drilling after that date), "paid out" in 5 years; and 100 per cent of the properties in group 1, class *b* (production more than 2 years old and new wells drilled), "paid out" in 4 years and 3 months. It is interesting to note that all the 9 properties "paid out" in 9 months less time than those properties whereon no drilling was done.

Of the 8 properties in group 2, class *a* (production less than 2 years old and no drilling done), 12 per cent "paid out" in 4 years and 5 months. The remaining 88 per cent had not "paid out" when the data were collected. Of the properties in group 2 (production less than 2 years old), 57 per cent of those in class *b* (drill-

ing done after purchase) "paid out" in 5 years and 1 month; the remaining 43 per cent had not "paid out" at the time the data were collected, this being about 6 years on the average after the date of purchase.

Table 2.—*Classification of the oil properties purchased in Illinois by an oil company, showing the percentage of those that had returned their cost and the length of time required.*

(1) Production more than 2 years old at date of purchase.				(2) Production less than 2 years old at date of purchase.			
(a) No drilling after purchase.		(b) New wells drilled after purchase.		(a) No drilling after purchase.		(b) New wells drilled after purchase.	
Paid out.	Number not paid out.	Paid out.	Number not paid. out.	Paid out.	Number not paid out.	Paid out.	Number not paid out.
Months.		*Months.*		*Months.*		*Months.*	
56	1	47		53	1	21	1
87	1	47			1	92	1
66	1	42			1	58	1
45	1	70			1	53	1
81	1	38			1	48	1
55	1	61			1	20	1
57		60			1	66	1
51		47				78	1
39		48				91	1
53						57	1
70						74	
57						66	
57						74	
774	6	460	0	53	7	798	10
Average, 5 yrs.	....	4 yrs., 3 mos.	....	4 yrs., 5 mos.	....	5 yrs., 1 mo.	....
Per cent paid out, 68.	....	100	....	12	....	57	....

Of interest is the accord in the length of time that most of these properties "paid out" and the lack of accord in the percentage of those that "paid out" under certain conditions. The average time of "paying out" ranged from 4 years and 3 months to 5 years and 1 month, whereas the percentage that "paid out" ranged from 100 per cent to 12 per cent.

PROPERTY THAT WAS SAFEST INVESTMENT.

It would seem from this analysis that under the circumstances prevailing at the time the safest property to buy was one on which the production was well "settled" and on which drilling could be done; also, that if at the date of purchase the production is comparatively young, it is a safer business venture to purchase those properties on which new wells can be drilled. Although the statistics given may not be applicable to other districts, and all the factors influencing the value of the properties have not been considered, yet at least the data furnish some interesting conclusions for that particular district.

APPRAISED VALUE AND SELLING PRICE OF OIL LANDS IN OKLAHOMA.

A few years ago the author helped to make an interesting valuation of several partly developed oil properties in the Osage Nation (Okla.). These properties were to be leased at public auction by the Federal Government, acting as agent for the Osage Indians, at a royalty of one-sixth, to the person bidding the highest bonus. The bidding was on a "barrel basis," or the amount per barrel of daily production (the working interest) that would be paid as a bonus. But the valuation was made by estimating the future annual production of each property with a specified future drilling program, allowing a certain remunerative rate of interest on the capital invested, and computing the present value of the deferred profits. It was estimated that the future price of oil would be slightly greater than the then existing price. The object of the valuation was to determine the minimum price at which the Government, acting for the Osage Indians, could afford to dispose of the leases.

Thus it was possible to compare directly the probable minimum value, as determined by one method of valuation, with the highest price, a group of operators felt should be paid for a property. In general, the prices paid per barrel were considerably above, and often two and three times, the minimum value set by the Government. This difference was probably due to the optimism of the purchasers in regard to the future price of oil and to the intense competition for oil leases in that part of Oklahoma. Fortunately the price of oil since has increased considerably, even more than was then expected, so that the investments probably have proved lucrative.

APPRAISAL METHODS.

GENERAL STATEMENT.

An oil property is appraised on the basis of the net returns to be obtained annually from it. Whether or not the deferred profits are discounted depends in a measure on the accuracy with which the future annual production is estimated. The purchase value of a property is the sum that will be paid back with interest to the investor before the oil is exhausted, and it is governed by all the conditions that control oil production, only a few of which have been discussed in the preceding pages.

In appraising the value of oil lands it is imperative that the undrilled part of a producing property be segregated and appraised on a different basis from the drilled part. Slow drilling ordinarily reduces the ultimate amount of oil that may be obtained from a property because of the accompanying drainage of the sand and the gradual reduction of gas pressure; so that a property is worth more

if it is to be drilled at once, for not only will the ultimate production probably be greater, but also the present value of deferred profits is greater, provided the price of oil does not change. Therefore, as a result of postponing the drilling of a property, a double factor militates against its value.

Many mathematical computations are involved in the valuation of oil lands, especially if a careful estimate is to be made of the value of many properties. Hence, there then may be great need of short cuts and rule-of-thumb methods. Such figures as the estimating chart (fig. 21) for determining future production quickly, would be of value if they could be so revised as to show the actual value of oil properties for different rates of drilling, for different future prices of oil, and the like.

METHOD OF APPRAISING SEVERAL SCORE PROPERTIES.

The author recently appraised several score oil properties for the Government, and because of the necessarily short time available the adoption of some system by which much of the tiresome mathematical work would be eliminated became imperative. The properties were in three different main districts, but the controlling conditions in each district differed radically. For instance, in district No. 1 were several wells; these partly proved the oil-bearing character of the geologic structure where they were drilled. In the second district several hundred wells were drilled which defined the probably productive area with fair accuracy. No wells had been drilled in the third district, and there a geologic report had to be used as the basis of the appraisal.

A part of the detailed work necessary for the appraisal of the properties in the second district is given here, because although they varied widely there was no great uncertainty, on account of the number of wells completed, as to the ultimate outcome of drilling. The properties to be appraised were all partly drilled, and the lack of detailed data made necessary the use of composite decline curves in estimating future annual production. All the properties lay on a large anticline and individual well-production records were available.

DATA PLOTTED OR COMPUTED.

In general the work consisted of (1) constructing a composite decline curve of the wells in the district; (2) projecting these composite decline curves and thus estimating the future annual production of the productive wells; (3) dividing the undeveloped territory into areas of varying productivity and estimating the probable ultimate production per acre of the different classes of undrilled land; (4) computing the first year's average daily production per well from the estimates of ultimate production per acre, as explained on page 54;

(5) estimating the average daily production per well the first year and checking against the computations made in (4); (6) assuming a certain drilling program to be instituted on each lease—if more than one class of acreage occurred on a lease, the richest was assumed to be drilled first; (7) computing the value of the oil obtained annually from one well of each class of acreage, deducting drilling and production costs, discounting the deferred profits, and allowing a certain remunerative rate of interest on the investment; and (8) determining the acreage per well and dividing with this figure the total undrilled acreage of a certain class. The number of wells to be drilled on each class of acreage multiplied by the net present value of the deferred profits from one well gave the present value of that class of acreage.

DETERMINING THE FUTURE PRODUCTION OF THE DRILLED AREA.

As already stated, the main object of the appraisal was to determine the total value of all the properties. A composite decline curve was computed for the producing wells. Seemingly the simplest method of determining the future annual production of the district was to determine at what point on the composite curve the field was producing; in other words, to determine the average age of a barrel of production in that field. Obviously it was impracticable to determine the average age of a barrel of production in the manner used by Washburne (p. 62), for several hundred wells were involved. Therefore it was decided to determine the average age by trial—by estimating the probable age of production and then applying the curve values for the past years and determining whether the total past production thus determined would equal the actual amount produced.

DETERMINATION OF PROBABLE AGE OF PRODUCTION.

The total past production of all the wells amounted to 72,000,000 barrels; the existing daily production of the district was 37,000 barrels, and the average age per barrel of production was at first estimated at about 4 years. The percentage readings on the composite decline curves for the first 4 years are in succession 100 per cent, 66 per cent, 51 per cent, and 41 per cent, so that if the daily production of the wells was approximately 37,000 barrels and the average age of production was 4 years, the first year's production of these wells would be 37,000 divided by 41 per cent, or approximately 90,300 barrels. This then was the average daily production for the first year if the present wells all began producing 4 years before. The first year's average daily output, or 100 per cent, was multiplied by the percentages for the second, third, and fourth years, and these products in turn by 365 (days in a year). The daily outputs obtained in this way were 90,300 barrels, 59,700 barrels, 46,300 barrels,

and 37,000 barrels successively for the 4 years, or a total of 233,300 barrels; this sum multiplied by 365 days gave a total production to date of 85,200,000 barrels. But the actual total production was approximately 72,000,000 barrels, showing that the assumed average age for a barrel of production was too great. The same method, using an assumed age of 3 years, gave too small a total output. A third estimate sufficed to determine rather closely the average age, which proved to be 3½ years. This average age gave the first year's average daily production as 82,200 barrels. This multiplied by 66 per cent and 51 per cent gave an average daily production of 54,500 barrels the second year and 42,200 barrels the third year, or a total average daily production for the first three years of 178,900 barrels; this average multiplied by 365 days gave a total production of about 65,300,000 barrels for the first three years. Adding the amount obtained by multiplying the first year's production by one-half the percentage for the fourth year, made a total production of 72,050,000 barrels for 3½ years.

RESULTS OBTAINED.

Although this method is merely an approximation, it served as a check on the estimates made by other methods. Similarly the approximate future annual production of the present wells was obtained by applying the values on the composite decline curve for all years following three and one-half years. The results are shown in the following table:

Probable future output, apparent net value, and present value as determined from the composite decline curve.

Year.	Estimated annual production of present wells.	Apparent net value after deducting production costs.	Present value (at 6 per cent).
	Barrels.		
Fourth	6,115,000	$4,280,000	$4,280,000
Fifth	10,100,000	7,070,000	7,280,000
Sixth	8,250,000	5,780,000	5,150,000
Seventh	6,760,000	4,740,000	3,980,000
Eighth	5,660,000	3,970,000	3,140,000
Ninth	4,830,000	3,380,000	2,530,000
Tenth	4,140,000	2,900,000	2,040,000
Eleventh	3,630,000	2,540,000	1,690,000
Twelfth	3,180,000	2,230,000	1,400,000
And so on to—			
Thirty-fourth	270,000	189,000	33,000
Total	78,085,000	....	39,128,000

APPARENT NET VALUES.

The apparent net values shown in the third column are deferred receipts; they were obtained by multiplying the annual production shown in the second column by 70 cents, which was assumed as the

net amount received, after deducting the costs, per barrel of oil produced. Although it was realized that this net value probably was low, a conservative estimate was desired. In view of the uncertainty of the price of oil at almost any future time because of increased production and drilling costs and of possible price fixing by the Government, the approximate net value per barrel the producers received at that time was used.

PRESENT VALUE OF DEFERRED RECEIPTS.

In the fourth column are the present values of these deferred receipts, so that the total of $39,128,000 represents the total present value of the oil to be produced by the existing wells on the assumptions of a certain future price per barrel of oil and certain production costs. This sum is what a prospective purchaser could afford to pay for the oil from the existing wells and yet have as much money at the end of the period as though he had invested otherwise in securities at 6 per cent. But oil-property investments are uncertain, and returns on them are speculative. Hence, the buyer demands a rate of interest on his capital commensurate with the risk of his investment, and this rate is high. Consequently, the prospective buyer of the property mentioned could not afford to pay the sum indicated.

DETERMINING THE FUTURE PRODUCTION OF THE UNDRILLED AREA.

The proved undrilled territory amounted to about 11,000 acres and the producing wells were scattered over the whole field, thus proving much undrilled ground. Hence, it was fairly safe to assign a certain ultimate production to each undrilled acre by comparing this value with the probable amount of oil to be obtained from the near-by drilled territory instead of classifying the acreage in accordance with the scheme given on page 81.

ASSUMPTIONS MADE.

Because it was necessary to use a single composite decline curve for all the wells to be drilled it was also necessary to assume that the output of all the wells would decline along this curve. This assumption probably introduced some error in the calculations, for the initial yearly output of the new wells would decline through interference, but the error was compensating. Now, if the ultimate production per acre of a tract of land is less than that of an adjoining tract, the initial yearly production of the new wells on the first tract will be less than that of those drilled on the second tract, so that different amounts of oil will be obtained annually from wells on tracts of different productiveness. Because of the depth at which some of the productive oil zones lie below the surface, it was esti-

mated that only 7,840 of the undrilled 11,000 acres would repay drilling.

The new wells were allotted 10 acres each, the drilling cost was estimated at $50,000 per well, and a drilling program of eight wells yearly on each tract of 640 acres was assumed, although it was realized that actual drilling probably would not proceed so rapidly. The time taken to drill the wells would influence slightly the present value, but the added refinement of computing this difference was incommensurate with the accuracy of the other parts of the estimate.

To determine carefully the present value of the oil to be obtained from such a large number of tracts would have been very laborious, and a chart (fig. 22) was prepared that greatly reduced the work required. Briefly, the chart was prepared by determining the total present value of the output of wells drilled during different years on tracts of varying productiveness. The total present value of the output of a well decreases with the deferment of drilling; furthermore, the total present value is less for a well drilled on acreage that ultimately will produce 10,000 barrels than that of a well drilled on a tract that ultimately will produce more.

Figure 22 was prepared by computing, for example, the total present value of the annual output from one well drilled during the present year on an undrilled tract that ultimately will yield 11,000 barrels an acre, and again, to determine the total present value of an identical well drilled a year hence, two years hence, three years hence, and so on, for eight years. When plotted on semilogarithmic paper these total present values for wells drilled in different years lie on a straight line, as shown in figure 22. Similar computations were made for the total present value of the output of wells drilled during different years on lands that ultimately would produce 20,000 barrels and 60,000 barrels per acre, respectively. The inclination of these three lines proved to be the same, and the additional parallel lines were determined by interpolation.

EXAMPLES OF USE OF CHART.

The chart was used as follows: If eight new wells were to be drilled during the first year on a tract of land, the total present value of their output was determined by multiplying the total present value of the output of one well by 8. Furthermore, if the tract was large enough to support eight new wells the second year and five the third year, the total present values of the output of the wells drilled during the second and third years were obtained by multiplying the present values of the output of one well drilled the second year by 8 and of one well drilled the third year by 5.

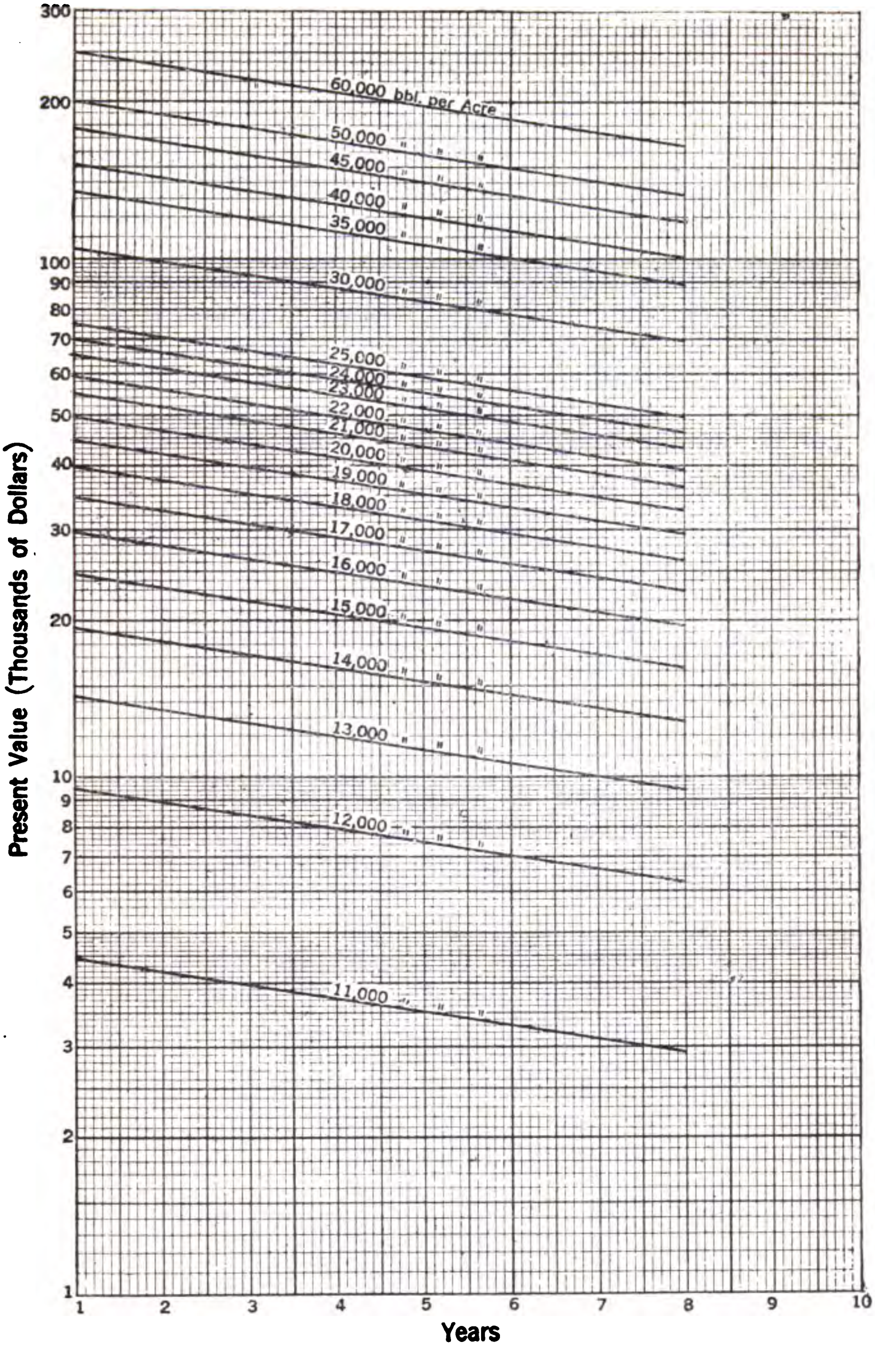

FIGURE 22.—Chart used in an appraisal of oil land for determining the total present value of the oil to be derived from wells drilled on acreages of different productiveness.

Again, suppose a property contains 330 acres of undrilled land, of which 230 acres, it is assumed, ultimately will produce 30,000 barrels per acre, and 100 acres ultimately will produce 20,000 barrels per acre. The best land will be drilled first, and it was assumed all the wells could be completed so that all would produce from the first of the year. If 10 acres are allowed for each well the 30,000-barrel acreage will support 23 wells, and the remaining acreage 10 wells. With the drilling program of eight wells a year, eight wells will be drilled during the first year on the 30,000-barrel territory, eight wells the second year, and seven wells the third year. The total present value of eight wells drilled the first year on 30,000-barrel land is 8 times $105,000 (fig. 22), or $840,000; that of eight wells drilled the second year is 8 times $98,000, or $784,000; and that of seven wells drilled the third year is 7 times $92,000, or $644,000. This gives a total present value of $2,268,000 for the output of wells drilled on the 30,000-barrel acreage.

As only seven wells were drilled during the third year, one well may be drilled on the 20,000-barrel land to carry out the drilling program of eight wells a year. By following the same procedure it can be shown that the present value of one well drilled the third year on the 20,000-barrel acreage is $44,000. Ninety acres of this class of land remaining gives eight wells to be drilled during the fourth year and one during the fifth year. The present value of eight wells completed during the fourth year on the 20,000-barrel acreage is 8 times $41,000, or $328,000; and that for one well completed during the fifth year is $39,000. Hence the total present value of all the wells drilled on the land with an ultimate production of 20,000 barrels an acre is $411,000. This sum added to $2,268,000 gives $2,679,000, or the total present value of the undeveloped acreage.

The reader should remember that on account of the lack of specific information it was impossible to take into consideration the inevitable decline in initial yearly production. If the initial yearly production should decline during the latter part of the drilling of any one lease, the ultimate production recoverable would of course be smaller. However, as a factor of safety, the estimate of the future price of oil was made rather low, and the estimates of ultimate production were modified to take care of this factor.

The example just given shows one of a variety of methods that may be used in determining the present value of the deferred receipts in large-scale oil-property valuation. It is not expected that the chart itself will be useful to others, for the conditions probably will not be duplicated.

COMPUTING DEPLETION FOR PURPOSES OF TAXATION.

GENERAL STATEMENT.

A subject that bears on the estimation of the ultimate output of oil properties is the determining of the deductions from gross income, because of the depletion of the recoverable oil, for the purpose of computing the income tax authorized by the revenue act of September 8, 1916, as amended by the act of October 3, 1917. Individuals and corporations owning oil or gas properties are authorized by this act to deduct from gross income[a] "a reasonable allowance * * * for actual reduction in flow and production, * * * provided that when the allowance authorized * * * shall equal the capital originally invested, or in case of purchase made prior to March 1, 1913, the fair market value as of that date, no further allowance shall be made."

The reason for this provision is that capital, being returned out of profits, shall not be subject to tax. Return of capital comes out of gross profit. Hence a deduction must be made from the gross profit in order to find the true profit (taxable income) made over and above all costs. It is intended as a relief of tax upon such part of the gross profits as represents a return of the capital invested.

DEPRECIATION AND DEPLETION.

Depreciation and depletion should be clearly distinguished. Deductions on account of both are made from gross income to determine what proportion of the income is subject to tax.

Depreciation covers loss through exhaustion and wear and tear of physical property, such as machinery, and the decline in value of lease rights. The annual depreciation allowed is determined by the probable life of the physical property.

Depletion, on the other hand, covers the decrease in the amount of natural deposits through production. The production of oil entails depletion of the natural deposits, and as long as production continues depletion allowances should be made.

The Treasury Department encountered considerable difficulty in the administration of the act of September 8, 1916, because of the various methods used by operators in determining depletion, and because of the operators being uncertain as to what procedure the Treasury Department wished them to follow.

[a] Regulations No. 33 (revised), governing the collection of the income tax imposed by the act of Sept. 9, 1916, as amended by the act of Oct. 3, 1917, Bureau of Internal Revenue, 1918.

METHOD FIRST REQUIRED BY TREASURY DEPARTMENT.

The method first set forth[a] provided that the annual deduction authorized by the provision quoted above "must be reasonable and not in excess of such a percentage of the cost or value, as the case may be, and as herein defined, of the oil or gas producing properties as is indicated by the reduction in the original flow or 'settled' production of one year as compared with that of the preceding year."

An example of the method set forth in T. D. 2447 is as follows:

If the decline in the flow and production during the year of, say, 10 wells, costing $100,000, has been 5 per cent, as compared with the production and flow as indicated by a test made at the beginning of the period, then 5 per cent of $100,000, or $5,000, will, for the year for which the compensation is made, constitute an allowable depletion deduction in favor of the individual or corporation owning and operating the property.

FALLACIES INVOLVED.

There are two inherent fallacies in this method of determining depletion. The first is that "settled" production is a comparative term only and not susceptible to a specific definition; the second is that if the aggregate flow of all the wells in a district for which depletion is to be determined is greater than the aggregate flow of the wells in the same district a year before (this often happens on account of new drilling), the book value will show an *appreciation* instead of a *depreciation*. Obviously this is absurd, for production means depletion, and wherever there is production the operator should have the privilege of deducting from his gross income a certain proportion of his invested capital. Thus, at the time when depletion is greatest no deductions from gross income are allowed.

METHOD USED BY SOME OIL COMPANIES.

BASIS OF METHOD.

Some of the larger oil companies operating east of the Rocky Mountains adopt a somewhat different method for computing depletion, but the results obtained are practically the same. The method consists of applying a certain unit value per barrel of oil, as was explained on page 85 in discussing the valuation of oil properties by the "settled" production method. For instance, a gage of the property to be purchased is taken for several days and the net daily production, exclusive of royalty and pipe-line deductions, is computed. Then the property is purchased for several hundred dollars a barrel, the sum paid per barrel depending on the probability of obtaining more production on the undrilled part of the lease, the age of the present production, the cost of development, and the like.

[a] T. D. 2447, Office of Comissioner of Internal Revenue, Feb. 8, 1917.

COMPUTING BOOK VALUE.

This same method is utilized in determining the book value of a property. If the property is undrilled the actual cost of obtaining the lease and the bonus paid per acre is, say, $5,000. The cost of developing oil is $5,000. The total cost is, therefore, $10,000. On the assumption that at the end of that year the production has declined to 25 barrels daily the unit value set per barrel becomes $10,000 divided by 25 barrels, or $400. If no drilling is done during the next year and production declines to 20 barrels daily, the book value of the lease will be $400 times 20 barrels, or $8,000. This value, as compared with the book value of the lease a year before, shows a depreciation of $2,000 which in this case includes depletion. On the other hand, suppose that by the expenditure of $10,000 the production increased during the second year to 60 barrels daily, then the total investment is $20,000, and the book value of the lease is $400 times 60, or $24,000. This method would make the book value of the lease show an appreciation of $4,000, although the oil deposits were depleted more during that year than if no wells had been drilled.

COMPUTING THE UNIT VALUE PER BARREL.

If a producing property is bought, the unit value per barrel paid would be adopted as the future unit value per barrel, and depreciation would be governed by that value. If the capital is not redeemed rapidly enough, the owners may find their property exhausted before the redemption fund is wholly realized; if the capital is redeemed too rapidly the owners are deferring the date at which they can obtain their profits.

Another point that should be brought out is the difficulty presented by the purchase of more than one property at different unit values per barrel of daily production. The value is computed in the following manner. Suppose 10 barrels of net daily production are purchased at a cost of $500 unit-value per barrel, a total value of $5,000, and that 20 barrels of production are bought for $800 a barrel, a total of $16,000. In the two properties the total investment becomes $21,000 for 30 barrels of production, or a unit value per barrel of $700. As properties are purchased at greater or less unit values per barrel, the average unit value per barrel is raised or lowered accordingly. Ordinarily, the same unit-value per barrel is maintained for each district where the operating conditions are similar, and if a company owns a large number of properties in different districts the depreciation is charged off for the properties as a whole in each district.

METHODS AT PRESENT REQUIRED BY THE TREASURY DEPARTMENT.

The regulations[a] recently issued authorize the use of either one of two different methods in computing depletion for the purpose of determining deductions from gross income. These methods apply: (1) Where the probable ultimate recovery of oil or gas is uncertain; (2) where the probable recoverable oil or gas can be estimated.

COMPUTING DEPLETION WHEN RECOVERY IS UNCERTAIN.

Under the first case the method required is that explained above, the percentage reduction in flow of wells on a property being computed at intervals of one year each. The objections to this method have been given.

COMPUTING DEPLETION WHERE PROBABLE RECOVERY CAN BE ESTIMATED.

Under the second case, the total amount of oil that will probably be recovered from a property is estimated, and such a percentage of the invested capital is deducted from the gross income as a year's production bears to the probable ultimate production. This has been called the "unit cost method," and obviously, this is the only method fundamentally sound for determining depletion. To illustrate its use, suppose a property will produce ultimately 100,000 barrels, and that during the first year of its life it produced 10,000 barrels, or one-tenth of the ultimate production, then the owner may charge off against gross income 10 per cent of the capital invested in the land.

To explain the designation "unit cost" we may use the same example. Suppose the property cost $20,000, and the gross income the first year was $30,000 from a production of 10,000 barrels. Because the property is estimated to be capable of producing 100,000 barrels ultimately, then the buyer has invested 20 cents in each barrel of recoverable oil underlying the property. This is the unit cost and the operator has the privilege of deducting this cost from the gross amount he derives from the sale. Here he derives $3 a barrel from each barrel produced. The same result is, of course, obtained by multiplying 10,000 by $0.20, which equals $2,000. This represents the amount of his deduction for depletion and he is allowed to subtract this amount from his gross receipts.

The amount of oil that a property may ultimately produce depends on the factors that govern the production of oil. Exact calculations of future or ultimate output can not be made, but the error introduced on this account is less than that involved in the use of the other

[a] Regulations No. 33 (revised), governing the collection of the income tax, 1918, imposed by the act of Sept. 9, 1916, as amended by the act of Oct. 3, 1917, Bureau of Internal Revenue, 1918. T. D. 2447, Office of Commissioner of Internal Revenue, Feb. 8, 1917.

method. All methods of computing depletion that are based on probable ultimate production can not be exact, although they are the only ones fundamentally sound and equitable to the oil producer.

The principal advantage of the method is that the rate at which invested capital is redeemed is in direct proportion to the rate at which oil is obtained, so that during the early life of a well when its production is nearly always largest, the depletion is greatest, and, consequently, the capital invested in the land is retired most rapidly.

The more speculative the production of oil, the more rapidly should the capital invested be retired. In other words, the estimates of ultimate recoverable oil should be conservative so that the production during any one year will be a larger percentage of the ultimate production, thereby allowing invested capital to be charged off more rapidly.

USE OF COMPOSITE DECLINE CURVES.

In using the second method of determining depletion, the operator must estimate the amount of oil he may ultimately recover from his property. Such an estimate is not difficult if the oil comes from only one well, for by projecting the curve showing the decline in output of that well, he is enabled to compute rather closely the ultimate production. The accuracy of his estimate increases as the well gets older. It is, therefore, advantageous when only a few wells are involved, to keep separate production records for each well, and to compute depletion for each. If a company operates several hundred or even several thousand wells such records are impracticable, especially if the daily production per well is small and the oil from several wells is run into one tank. Then some other method must be used.

One method is to estimate the probable ultimate amount of oil to be recovered by use of a composite decline curve showing the average rate of the decrease of production of wells in a certain district. The method of making such estimates from composite decline curves, and the advantages and disadvantages in their use have been fully explained.

USE OF APPRAISAL CURVES.

Appraisal curves may be of use for quickly estimating the ultimate output of oil from several hundred or several thousand wells in a district where conditions are similar, the average daily production per well on each property, or for the whole district, is determined and then the future production of the average well is multiplied by the number of wells. The ultimate production is obtained by adding the future and past production. In this way depletion may be computed for many wells and properties with no great difficulty and with considerable accuracy.

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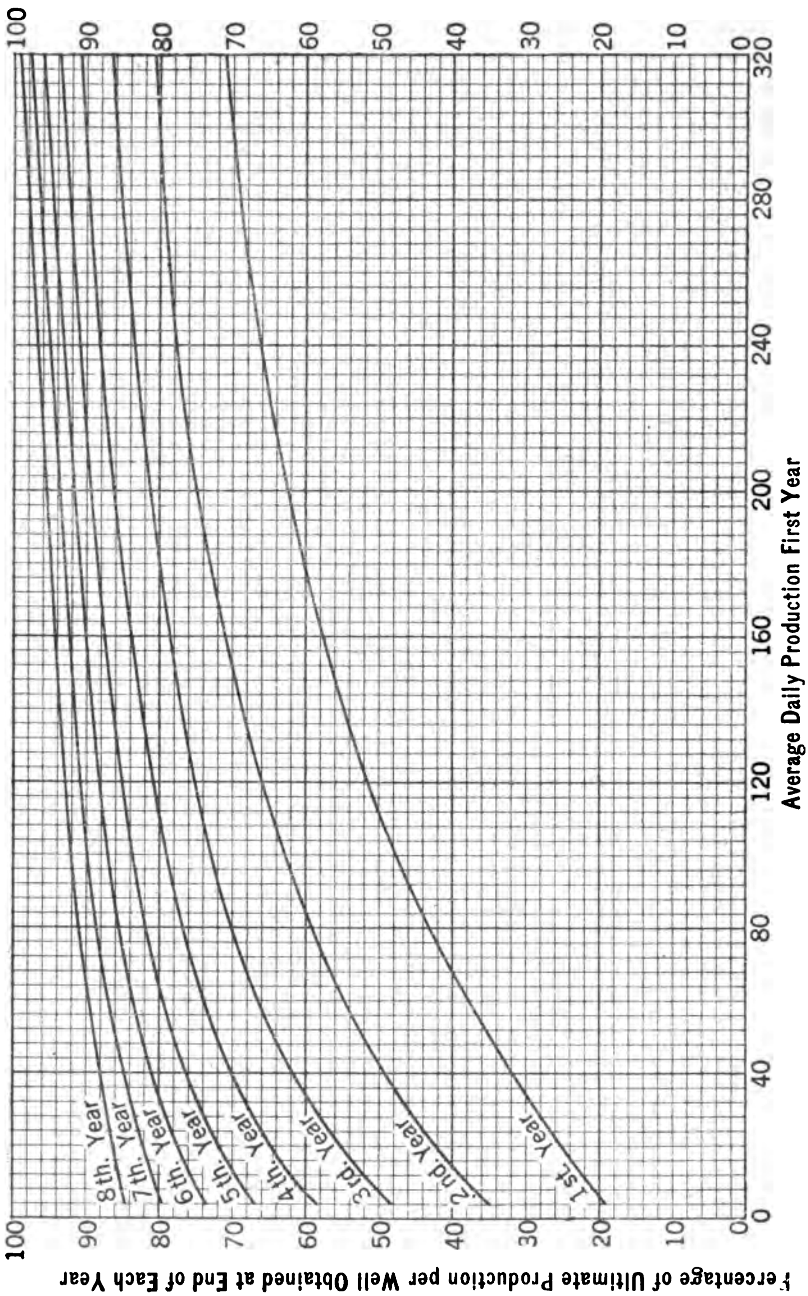


FIGURE 23.—Chart for rapidly computing the depletion of oil production of the properties in eastern part of the Osage Indian Reservation, Okla.

Figure 23 [a] has been prepared for the purpose of rapidly computing depletion. This chart shows the percentage of the probable ultimate production that will be obtained from wells of different output at the end of each year in the eastern part of the Osage Nation (Okla.). For instance, a well that yielded during its first year 100 barrels per day will have made at the end of that year about 48 per cent of its ultimate output. In other words, 48 per cent of the capital invested in the land drained by the average well of this size should be deducted from the gross income of the oil produced by the well during the first year. Similarly, the same well will have yielded at the end of the second year 63 per cent, and the third year 73 per cent of its ultimate production. Like charts for any other district may be computed directly if an appraisal curve is available. The ultimate production of wells of different output are computed from the appraisal curve and the total amounts produced during succeeding years are expressed as percentages of the ultimate production. These points are plotted and curves are drawn, as shown in figure 23.

If a property yields oil from wells of widely different output and ages, the average age of a barrel of production may be computed, and figure 23 utilized by interpolating this average age between the curves showing the years and along the vertical lines showing average daily production the first year.

CURVES SHOWING THE PRODUCTION OF A PROPERTY.

One of the simplest methods of estimating the amount of oil recoverable from a property is to plot a curve, as explained on page 68 showing the average daily or yearly production per well. After the property is partly drilled and interference through drainage has shown itself, the curve begins to decline and regardless of the amount of new drilling the average production *per well* continues to fall off. By projecting this curve to the minimum economic production, estimates of the property production for each time period may be made. One of the greatest advantages of using this method, at least for a check on other methods, is that by its use the making of estimates of the future initial yearly production of new wells becomes unnecessary, because for all practical purposes the initial yearly production of the new wells will be approximately the same as the average production per well of the old wells at any time. Theoretically, therefore, the postponement of drilling the remaining locations means the gradual reduction in the amount of oil that may be expected from these wells. This is known to be true, as a general rule, from experience.

[a] First published as figure 10 in "Some new methods for estimating the future production of oil wells by J. O. Lewis and C. H. Beal, Trans. Am. Inst. Min. Eng., vol. 59, 1918, p. 516.

PART 2.—DECLINE AND ULTIMATE PRODUCTION OF DIFFERENT OIL FIELDS IN THE UNITED STATES.

INTRODUCTION.

Few of the numerous publications on petroleum in this country deal with the rate of decline and the ultimate production of oil lands. Information is plentiful, but it must be gathered and analyzed and put into a form of use to operators and engineers who desire to predict the future of wells or properties under certain conditions. The need of such information is becoming more evident to the operator as the margin of profit per barrel of oil decreases and he realizes that only through careful engineering supervision, long since recognized as essential in all important industries, can he conduct his business profitably.

This bulletin is to be regarded as only a start in the systematic compilation of such material and the methods it presents can be amplified and extended in studying data from other fields. All the data given are not of the same value, and some of the information is discussed much more thoroughly than the rest. For instance, all the fields of the country were not studied in the same detail as were the Oklahoma fields. This fact applies especially to the California fields, although they deserve careful study because of the variable conditions of production and because of the wealth of information available to the engineer who can spare the time to collect it.

In part 1 the author outlined a few methods for estimating the future and ultimate production of oil properties and the possible use of these methods for several allied purposes. In part 2 are composite curves, appraisal curves, estimating charts and other collected material on the decline and ultimate production of different properties and fields. Because of the lack of information, appraisal curves and estimating charts have not been given for many of the fields for which composite decline curves have been constructed.

THE OKLAHOMA-KANSAS DISTRICT.

GENERAL STATEMENT.

The fields of the Oklahoma-Kansas district lie chiefly in northeastern Oklahoma and southeastern Kansas. Their productive sands are mainly in rocks of Pennsylvanian age, on the great westward and northwestward dipping monocline formed in the uplifting of the

Ozark Mountains in southwestern Missouri and northwestern Arkansas. At the Kansas-Oklahoma line the beds dip west about 30 feet to the mile. The Ozark uplift probably caused much of the major folding in both Oklahoma and Kansas. Generally, these folds trend with the strike of the formations, the character of the folds seeming to change, however, as one approaches the center of uplift. For instance, in the Bartlesville and Nowata districts, Okla., the folding of the oil-producing formations is not so marked as it is farther west. The general geologic structure of the Oswego limestone in a part of northeastern Oklahoma is shown in Plate I.

Many of the folds, such as those in the Cushing, Blackwell, Augusta, and Eldorado fields, have been considerably modified by folding subsequent to the Ozark uplift. For instance, two separate series of cross folds along the north and south Cushing uplift have already been pointed out.[a]

The Healdton field, in southern Oklahoma, has not been studied in detail, but the conditions affecting the origin of the fold and the accumulation of the oil and gas are probably in no way related to those that govern the distribution of the oil pools in northeastern Oklahoma and southeastern Kansas. However, the Healdton field is included in the Oklahoma and Kansas district.

SPACING OF WELLS IN OKLAHOMA FIELDS.

In the Oklahoma oil fields 10 acres are ordinarily allotted each well, where the sands are more than 2,000 feet deep. If the sands are between 1,000 and 2,000 feet deep, the custom is to drill one well for every five or six acres, and for sands less than 1,000 feet deep, one well for approximately four or five acres. However, this practice is not strictly followed. In 1915 the average acreage per well on the restricted Indian leases of the following Indian nations in Oklohoma was determined by the author to be as follows:[b]

Average acres per well in the Cherokee, Chickasaw, and Creek Nations, Okla.

Indian nation.	Average acres per well.	Number of wells used in obtaining average.
Cherokee	5.1	4,500
Chickasaw	[c] 14.8	19
Creek[d]	7.4	917
Cushing field	7–10	584
Entire State	5.7	6,020

[a] Beal, C. H., Geologic structure in Cushing oil and gas field, Oklahoma, and its relation to oil, gas, and water: U. S. Geol. Survey Bull. 658, 1917, pp. 34–35.

[b] From a report of the author to the Superintendent of the Five Civilized Tribes, June 30, 1916.

[c] Drilling only begun at time of determining average.

[d] Excluding the Cushing field.

These averages were obtained without regarding the depth of the sand in different parts of the State. In the Cherokee Nation the wells ranged in depth from 300 to 400 feet to about 2,000 feet.

OSAGE INDIAN RESERVATION.

GENERAL DATA.

Some information on the Osage Indian Reservation has already been presented in a preliminary paper by Lewis and Beal [a] and some of this is republished here in revised form. Most of the oil and gas wells have been drilled in the eastern part of the reservation, and the figures compiled were for properties in that district. Records of the production of 68 of these properties, including more than 1,000 wells, were studied and analyzed. The properties are scattered over a district 60 miles long and 20 miles wide, so that the conditions affecting production differ greatly. Depths range between wide limits, and the geologic structures on which the oil has accumulated are rather diverse, so that a great variety of data was at hand.

Most of the oil comes from the Bartlesville sand in the lower part of the Pennsylvanian series. The depth of the sand ranges from 1,500 to 2,500 feet, and the average area allotted to each well is approximately 10 to 12 acres. Such differences in depth and the comparatively large acreage for each well cause considerable differences in the initial production and the rate at which the oil is obtained. The first year's average daily production per well, of the wells for which records were available, is about 35 barrels, the range being from three to four barrels to more than 300 barrels.

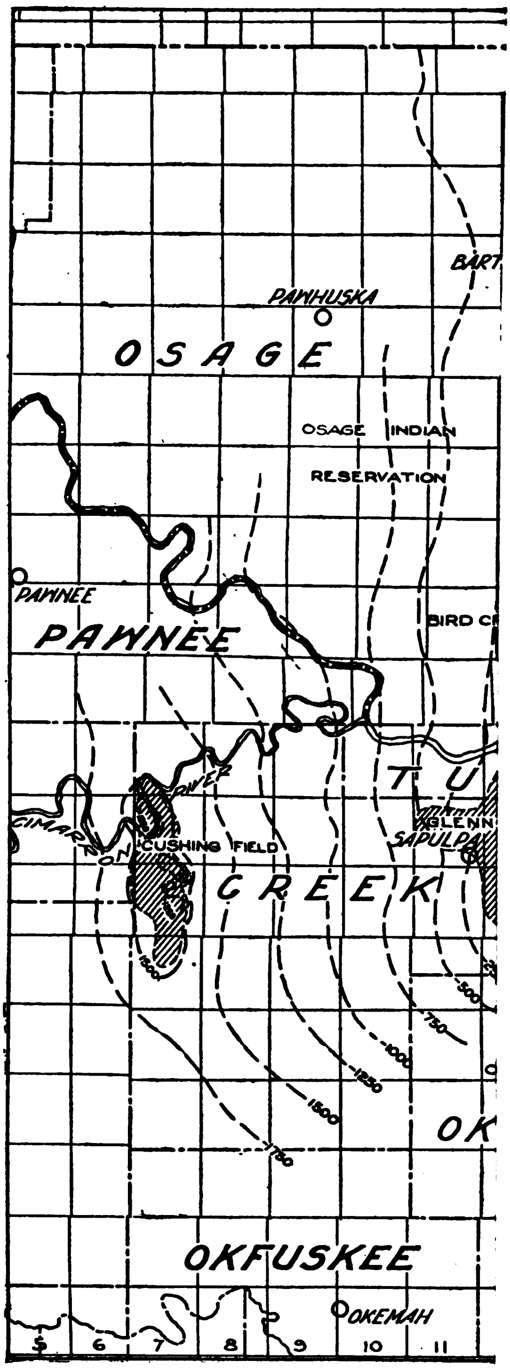
APPRAISAL CURVE.

Figure 24 shows the appraisal curve for this field. The construction and use of appraisal curves have been explained previously. The maximum and minimum ultimate production curves do not establish such narrow limits as some of the other appraisal curves because of the variety of conditions affecting output and because of the properties being scattered over a large area.

COMPOSITE AND GENERALIZED DECLINE CURVES.

Figure 25 represents the decline of the average well in the eastern part of the Osage Nation. If the first year's average daily production per well on a property is 100 barrels, during the second year the average output will be a little more than 63 barrels daily. The

[a] Lewis, J. O., and Beal, C. H., Some new methods for estimating the future production of oil wells: Am. Inst. Min. Eng. Bull. 134, February, 1918, pp. 477–504.



SKETCH MAP OF NORTHEASTERN OKLAHOMA, S
FIELDS AND THE GENERAL GEOLOGIC STRUC
LOGS.

number of properties used in determining this average curve is shown along the curve. The generalized decline curve for the Osage Nation (fig. 16) was discussed on page 64.

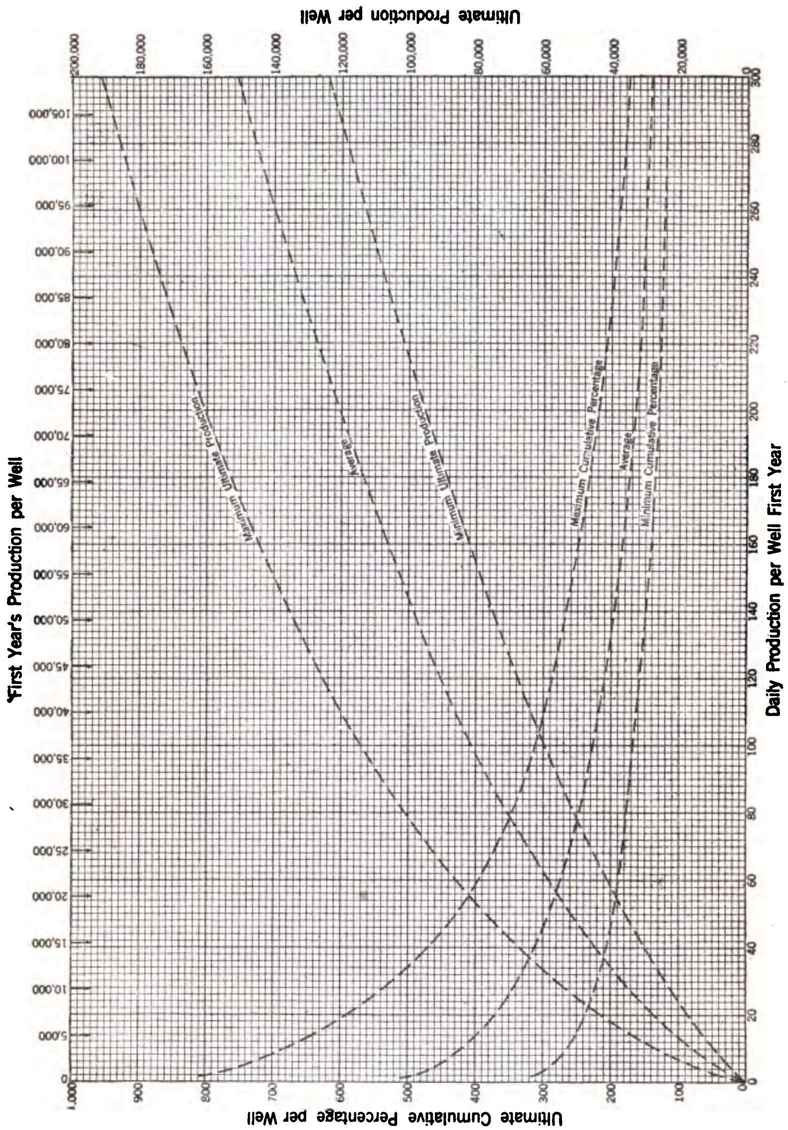


FIGURE 24.—Appraisal curve for the Osage Indian Reservation, Okla.

ESTIMATING CHART.

Figure 26 shows a chart prepared for rapidly estimating the approximate amount of oil that will be produced by wells that have produced a certain amount of oil and have a certain age. Such

charts have been explained on pages 76 to 80. Figure 26 should be used with caution because it applies to a large area where new pools may produce oil under different conditions.

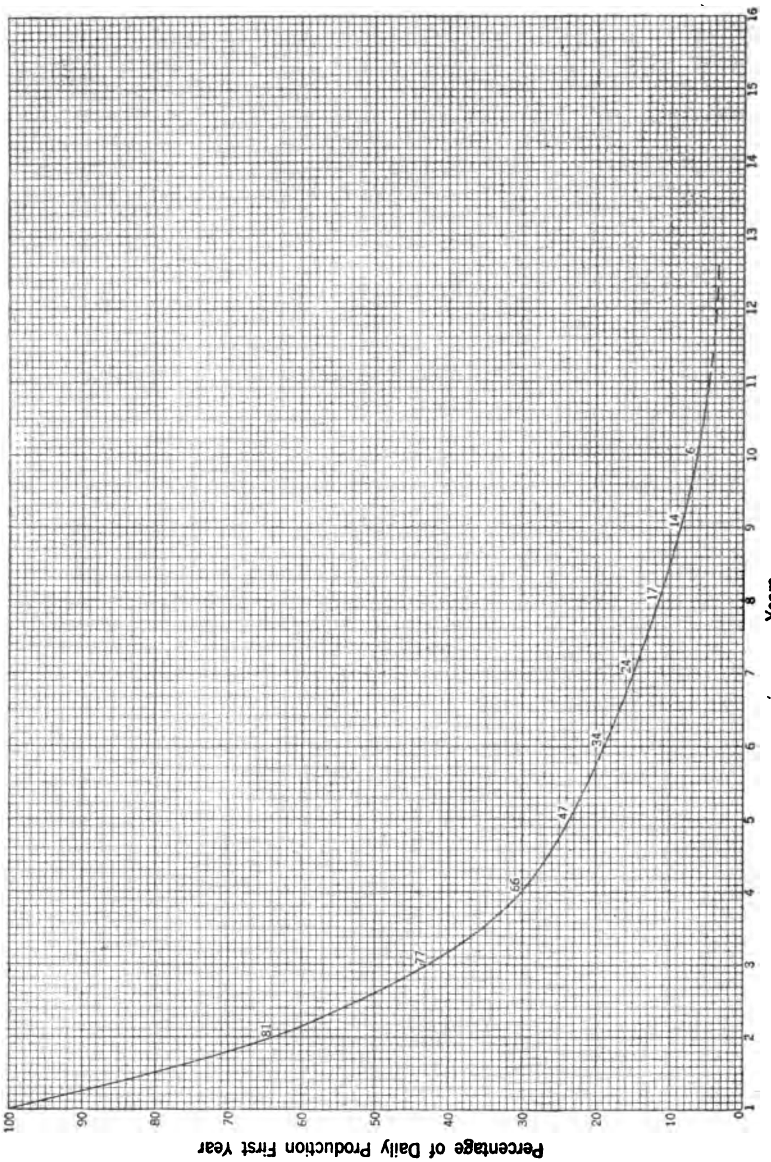


FIGURE 25.—Composite decline curve of the wells in the eastern part of the Osage Indian Reservation, Okla.

ACREAGE CHART.

Figure 27 shows the ultimate cumulative percentage for average wells on different properties plotted against the average acres per

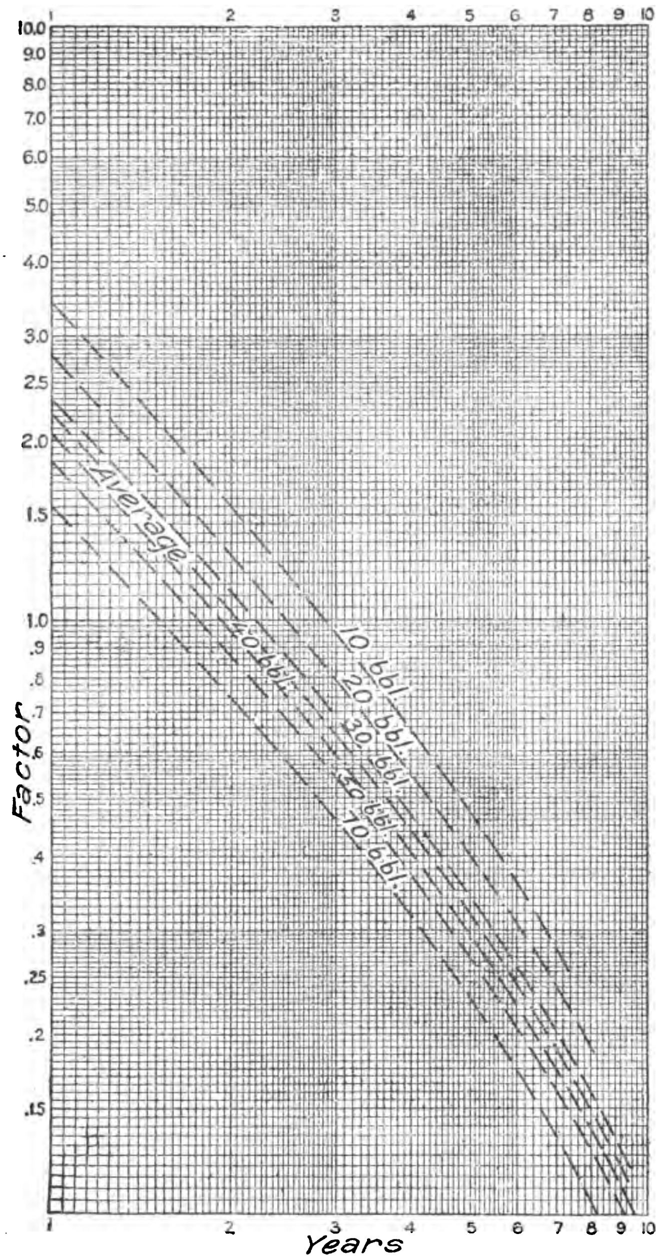


Figure 26.—Estimating chart for the properties in the eastern part of the Osage Indian Reservation, Okla.

well. The use of such charts for making closer estimates of the probable future production has been explained on pages 56 to 58.

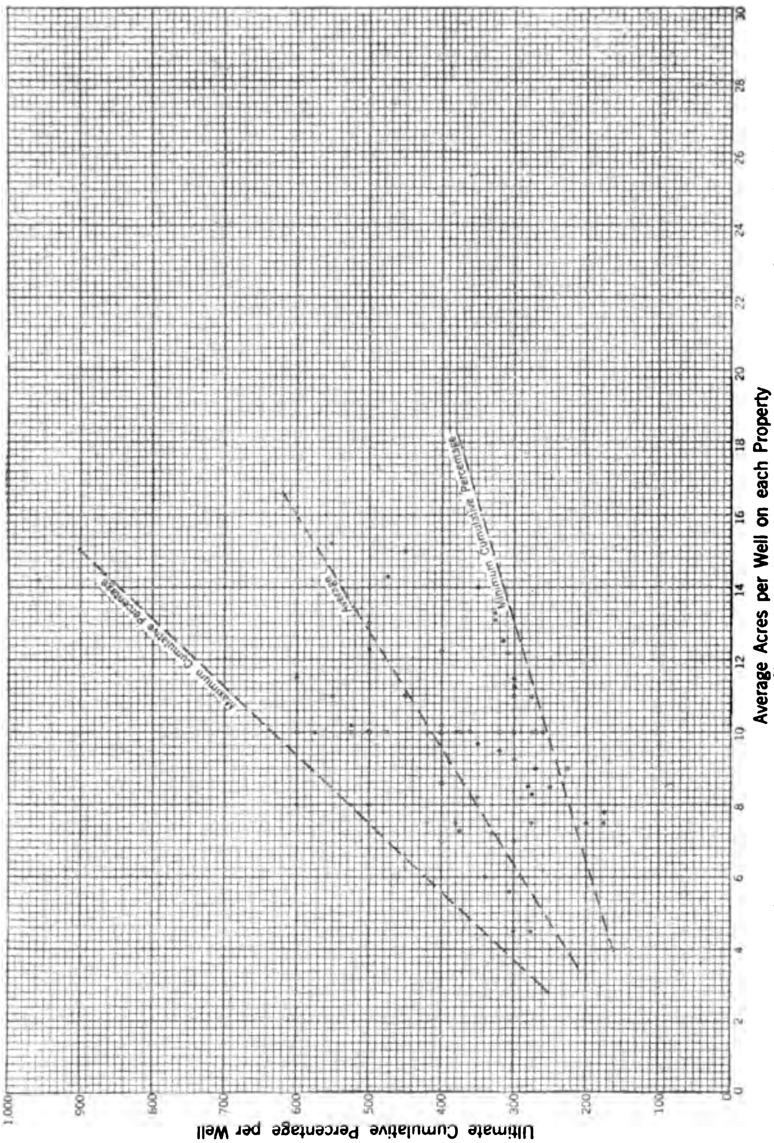


FIGURE 27.—Relation of average acreage per well to the ultimate cumulative percentages of wells in the eastern part of the Osage Reservation, Okla.

AVERAGE TOTAL PRODUCTION PER ACRE.

Prior to June 30, 1917, the Osage Nation produced more than 91,500,000 barrels of oil, the first recorded output having been in

1901. The area drained by productive wells is approximately 30,000 acres, so that the average total production per acre is approximately 3,000 barrels. It should be remembered that much of the production included in the total output is only a few years old, and that the wells producing this oil will yield more in the future, so that the ultimate production of the Osage Nation will be considerably more than 3,000 barrels per acre.

THE BARTLESVILLE FIELD.

DATA COLLECTED.

The Bartlesville field (Pl. I, p. 106) covers a large area, about 45,000 acres, and includes many different pools of oil lying on different geologic structures and occasionally in different sands. The field has been taken to include all wells between the Nowata-Chelsea field and the boundary line between the Osage and Cherokee Nations, and to extend as far north as the Kansas line. Because it is one of the oldest producing fields in Oklahoma, the field furnished much information, the records of more than 300 properties being available. As a whole, the district is divided into many small holdings because of the small size of the tracts allotted to the Cherokee Indians when the land was divided among the members of that tribe. Many of the leases are not larger than 10 acres, so that drilling has been rather close, and on many of the 10-acre tracts four wells have been drilled. However, the average area per well in the field is five to seven acres. Most of the oil comes from the Bartlesville sand, which lies near the base of the Pennsylvanian series, of Carboniferous age.

In the Bartlesville field the conditions affecting production are by no means so variable as those in the Osage Nation a few miles west. About the only factor common to the two pools is that both produce chiefly from the Bartlesville sand, which here is 500 to 1,700 feet deep. For several hundred wells in the Bartlesville pool the average daily production per well the first year is 17 barrels, ranging from 2 to about 150 barrels. A production of about 20,000,000 barrels has been obtained from 306 properties having a total productive territory of about 11,000 acres, or an average output of about 1,800 barrels per acre.

APPRAISAL CURVE.

Figure 28 represents the appraisal curve for the Bartlesville field. Because of the large number of properties available and the age of the production on most of the properties used, which allowed a more accurate estimate of ultimate cumulative percentages, the appraisal curve can be used without much fear of inaccuracy.

COMPOSITE DECLINE CURVE.

Figure 29 shows the average decline of wells of all sizes in the Bartlesville field. On account of the many properties used in its

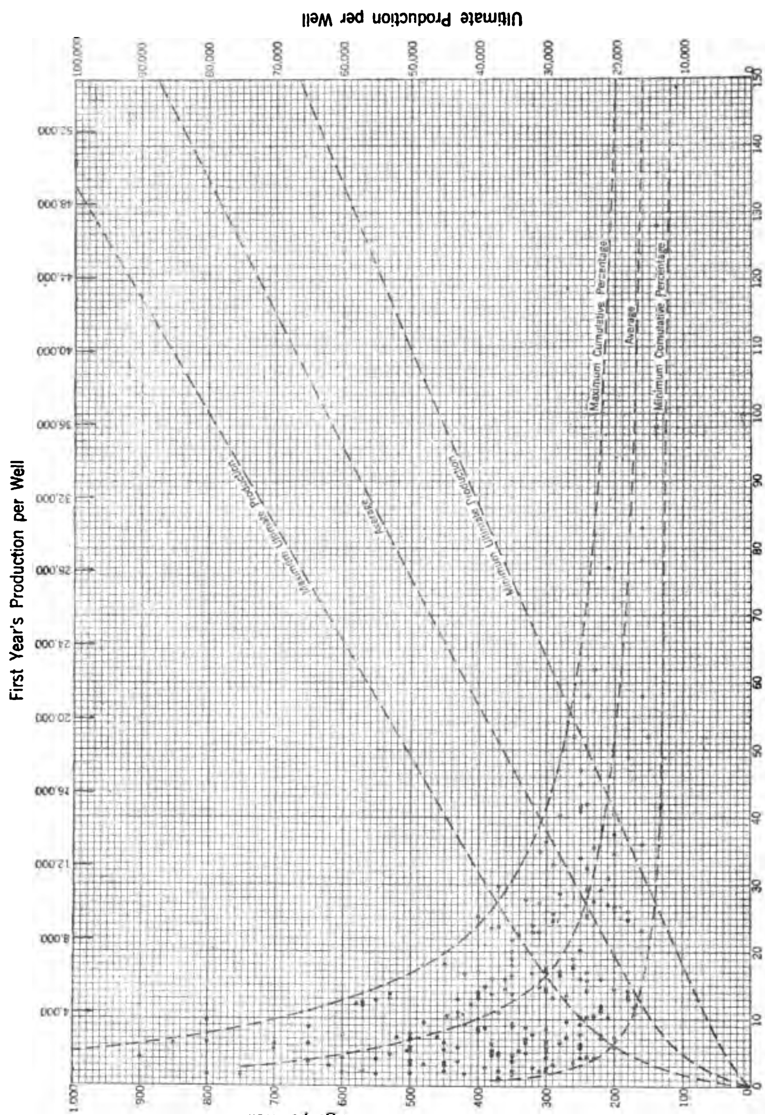


FIGURE 28.—Appraisal curve for the Bartlesville field, Okla.

construction, this curve may be used with confidence, although, as already pointed out, the accuracy of estimates made with such average curves will vary considerably because of differences in the rates

of decline of large and small wells (fig. 4, p. 26). Estimates of future and ultimate production will be in error in practically all curves for large wells and for small wells, but will be more nearly correct for average-sized wells. For such estimates an appraisal curve, if avail-

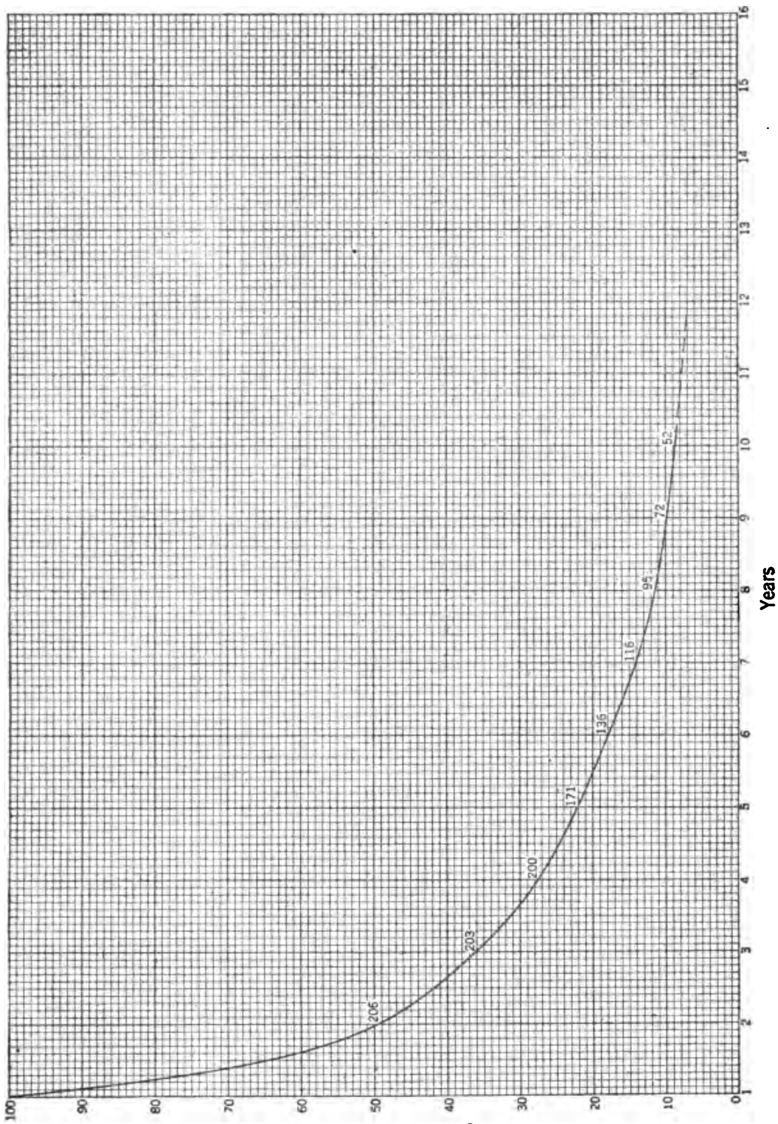


FIGURE 29.—Composite decline curve for the Bartlesville field, Okla.

able, is much better; a well yielding an average of two barrels daily the first year will decline more slowly than a well averaging 150 barrels daily the first year. These are the maximum and minimum

figures for the Bartlesville field. The numbers at yearly intervals on the curve (fig. 29) represent the number of properties employed in

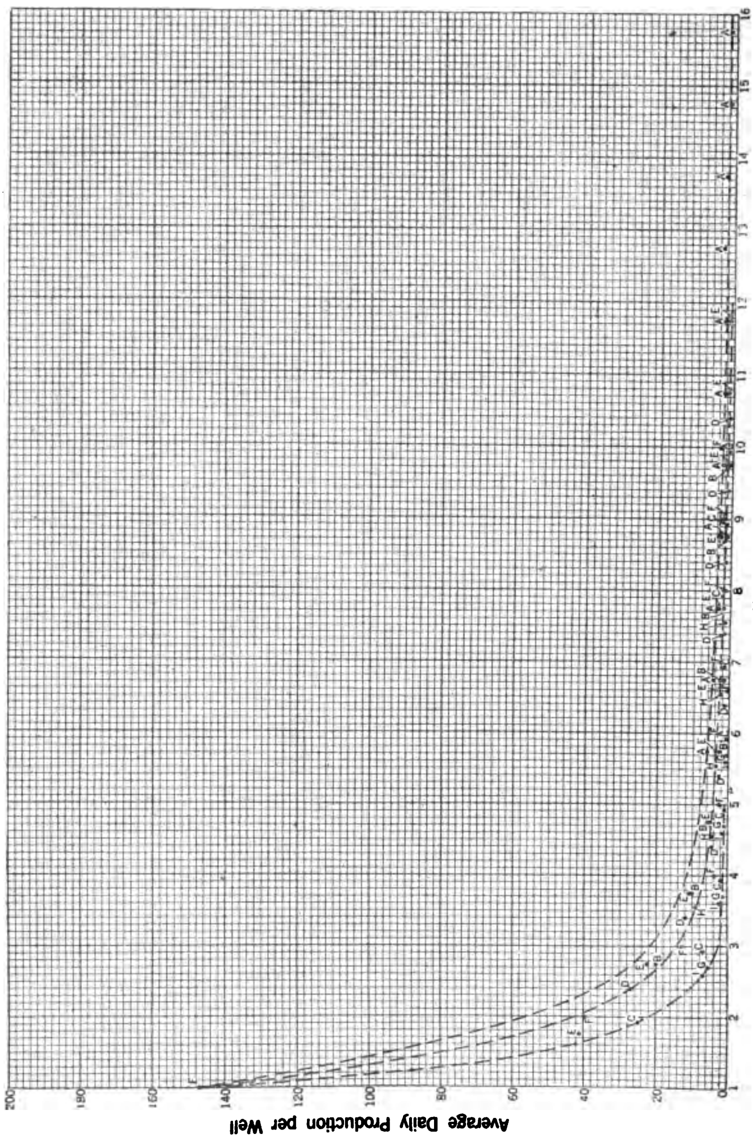


FIGURE 30.—Generalized decline curve for the Bartlesville field, Okla.

determining the averages of each year. No estimating chart was prepared for the field.

GENERALIZED DECLINE CURVE.

The generalized decline curve shown in figure 30 has already been ·xplained. It is used in estimating the future production of wells

of various sizes and is based on the law (see page 36) that wells of equal output will have the same future output regardless of their age. Given the first year's average production of a well, one is justified by the law of averages in plotting the output on the average curve shown in figure 30 and assuming that the decline of the well will follow the average curve. Thus the future production can be estimated. However, after the average daily production for one or more succeeding years has been obtained, more accurate estimates may be made by fitting the production curve of the well to the type of curve it most likely will follow.

The lettered data represent the actual decline of several properties in the Bartlesville field, the first year's average daily production being plotted on the curve that it seemed to follow best. This is further proof of the law advanced by Lewis and Beal[a] that wells of the same settled output will produce on the average approximately the same amount, regardless of their ages.

CHART SHOWING VARIATION IN SAND THICKNESS.

Figure 31, which gives the average thickness of sand underlying different properties, is reproduced not so much for its value in limiting the estimates of future output of properties in the Bartlesville field as for its showing the great range of ultimate cumulative percentages for sands of the same thickness. For instance, a well producing from a sand 24 feet thick will ultimately yield a minimum of about 135 per cent and a maximum of about 615 per cent of its first year's production.

Such wide differences in the productivity of sands of the same thickness prevent the use of this chart, with a few possible exceptions, in estimating future and ultimate production. The differences shown undoubtedly result from the chart covering a large area. Moreover, in some parts of the field, oil is obtained from other sands than the Bartlesville. Probably these sands differ in porosity, in gas pressure, in thickness, and in character.

RELATION OF ACRES PER WELL TO ULTIMATE CUMULATIVE PERCENTAGE.

Figure 32 shows the relations of the average area per well on different properties to the ultimate cumulative percentages of the average well on these properties. These curves will very likely be of assistance in limiting estimates of future production from different properties.

[a] Lewis, J. O., and Beal, C. H., Some new methods for estimating the future production of oil wells: Am. Inst. Min. Eng. Bull. 134, February, 1918, pp. 477–504.

DATA ON TOTAL AND ULTIMATE PRODUCTION.

Table 3 shows the total production per acre of several hundred leases in Oklahoma, and gives considerable information on the total

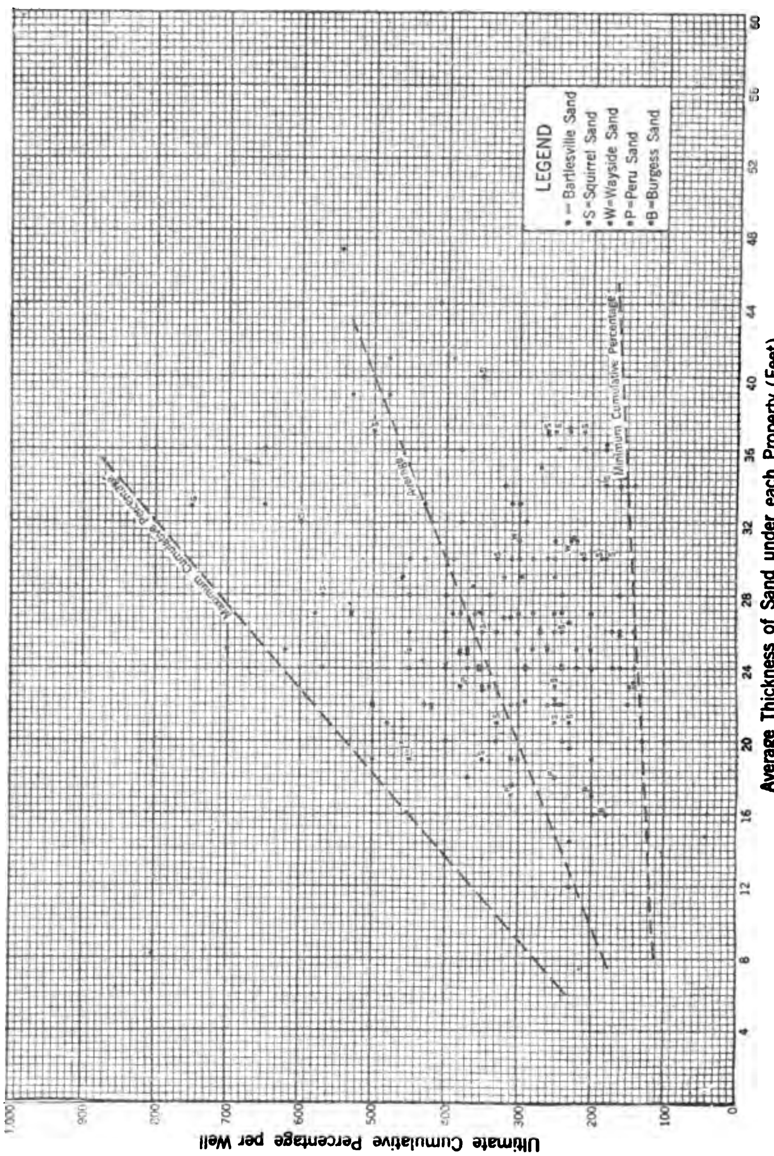


FIGURE 31.—Relation of the average thickness of sand underlying the different properties in the Bartlesville field, Okla., to their ultimate cumulative percentage.

yield per acre of different properties in the Bartlesville field. The reader should note that the average age in the fourth column of this

table is the average obtained by determining the number of years the first productive well on a lease has produced. As a matter of fact, a

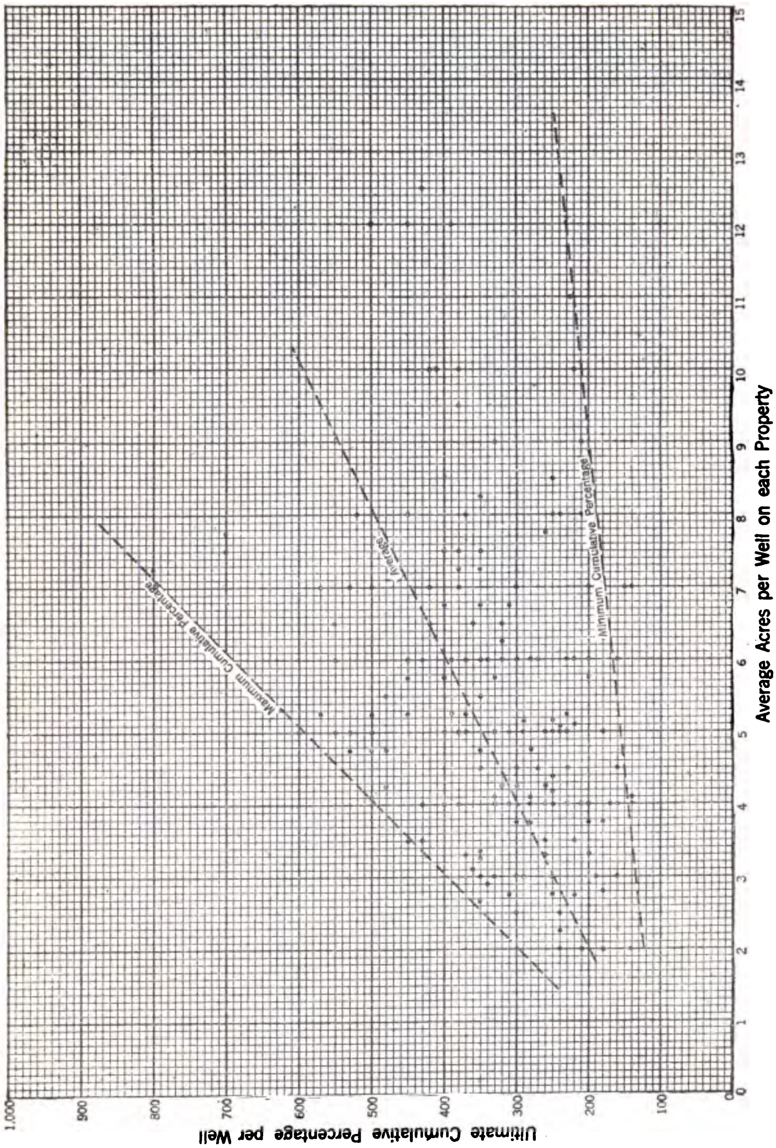


FIGURE 32.—Relation of average acreage per well to the ultimate cumulative percentages of wells in the Bartlesville field, Okla.

large part of the output from a lease may have come from wells drilled since, so that in general the age will be less than that given.

TABLE 3.—*Average total production per acre of leases in several hundred sections of land in Oklahoma.*

Township.	Range.	Section.	Approximate average age.	Average total production per acre.	Number of leases used in determining average.	Township.	Range.	Section.	Approximate average age.	Average total production per acre.	Number of leases used in determining average.
			Years.	*Barrels.*					*Years.*	*Barrels.*	
29 N.	12 E.	27	6	1,700	2	27 N.	13 E.	33	10	3,800	3
		34	4	2,000	2			34	8	2,700	4
	13 E.	31	8	700	3			35	4	800	1
		34	8	5,000	1			36	3	300	1
		35	5	700	1		14 E.	1	2	500	1
	14 E.	17	12	3,800	1			2	1	300	1
28 N.	12 E.	12	4	500	3			5	5	200	1
		25	$6\frac{2}{3}$	700	3			7	9	2,500	4
		35	4	900	1			12	6	1,100	2
		36	7	3,200	2			17	3	900	1
	13 E.	1	9	2 ,000	1			18	8	1,900	7
		6	5	870	3			19	5	1,400	2
		7	$4\frac{1}{3}$	400	3			20	5	400	2
		10	$6\frac{3}{8}$	800	5			30	5	300	1
		11	11	11,000	1		15 E.	3	7	7,900	1
		14	7	400	1			7	6	3,900	1
		20	4	100	1			16	6	500	1
		21	10	1,900	2			17	7	5,200	4
		22	$5\frac{2}{3}$	1,600	3			18	6	5,900	1
		26	6	340	1			20	7	4,000	4
		27	9	4,600	3			21	3	800	1
		28	5	700	1			22	7	1,500	4
		29	5	870	3			24	7	3,000	1
		30	4	100	1			26	7	900	2
		31	12	4,000	1		16 E.	19	8	1,000	1
		32	4	300	1			25	10	2,700	1
		33	12	1,000	1			26	10	5,900	2
		34	5	700	2			27	8	5,400	1
	14 E.	17	6	300	1			28	8	2,400	1
		20	3	500	1			32	10	2,300	1
		29	5	400	2			34	10	8,500	2
		30	4	700	3			36	10	6,000	2
		34	3	1,100	1		17 E.	31	10	4,400	2
	15 E.	16	5	500	1	26 N.	12 E.	11	10	2,105	1
		17	5	400	1			12	14	3,690	4
27 N.	12 E.	1	4	1,200	1			13	10	2,570	1
		2	4	300	2			14	11	4,525	1
		12	7	800	2			23	8	2,645	1
		13	4	1,200	1			24	10	3,220	1
		14	7	3,400	2		13 E.	1	5	1,897	4
		23	13	1,900	2			2	7	1,360	1
		24	12	6,400	2			3	7	2,700	3
		25	11	3,600	2			4	10	2,900	4
		26	11	3,555	2			6	1	80	1
	13 E.	1	6	900	3			7	13	3,000	1
		2	4	900	3			8	9	800	2
		3	5	600	2			9	11	9,800	3
		4	6	1,600	2			11	6	440	1
		5	10	2,100	4			12	6	690	4
		6	9	3,700	2			13	4	2,800	1
		7	12	3,000	2			14	5	600	2
		8	7	1,500	2			17	7	550	1
		9	11	2,400	1			18	9	3,400	4
		11	8	2,100	1			19	5	200	1
		12	8	1,500	4			20	9	1,000	4
		14	10	3,500	1			21	9	1,900	2
		15	9	1,500	1			22	5	1,500	2
		16	5	1,400	2			23	7	1,700	2
		17	9	760	3			24	5	360	1
		18	12	2,300	4			25	7	1,400	3
		19	11	1,900	3			26	6	1,300	2
		20	9	1,200	3			27	6	950	2
		22	8	800	3			28	6	400	1
		23	5	400	2			29	9	1,200	3
		24	5	570	6			33	6	1,400	2
		25	11	2,000	2			34	7	80	2
		27	8	3,200	5			35	6	300	2
		29	3	400	1			36	5	3,000	1
		32	5	800	1		14 E.	5	6	1,500	1

TABLE 3.—*Average total production per acre of leases, etc.*—Continued.

Township.	Range.	Section.	Approximate average age.	Average total production per acre.	Number of leases used in determining average.	Township.	Range.	Section.	Approximate average age.	Average total production per acre.	Number of leases used in determining average.
			Years.	*Barrels.*					*Years.*	*Barrels.*	
26 N.	14 E.	6	5	600	3	25 N.	17 E.	4	4	900	1
		7	6	1,800	3			18	9	1,400	2
		16	4	2,800	1			20	10	1,200	2
		18	6	960	3			21	12	3,100	1
		19	10	1,500	2			28	11	2,300	3
		21	4	3,100	1			29	11	870	1
		27	4	1,500	1	24 N.	12 E.	2	9	1,600	2
		30	10	4,600	1			11	4	1,300	1
		31	9	2,100	5			14	9	1,600	1
		33	6	800	1			23	9	6,000	2
		35	4	300	1		16 E.	12	11	9,100	1
		36	5	2,100	5			13	6	1,100	1
	15 E.	1	9	840	2		17 E.	2	8	1,370	1
		2	8	3,400	1			5	11	2,900	3
		11	2	290	3			9	9	2,400	2
		13	6	600	2			16	10	1,500	7
		29	3	250	3			17	11	2,400	5
		30	4	500	1			20	10	4,000	3
		31	5	500	1			21	2	5,100	1
	16 E.	2	9	6,400	1			22	3	8,500	1
		3	8	600	2			27	2	1,800	2
		7	3	600	1			30	1	80	1
		12	10	2,400	2		18 E.	1	2	510	2
		13	9	1,700	1		19 E.	6	4	990	1
		14	9	1,000	1	22 N.	12 E.	26	7	3,900	2
		15	11	900	1		13 E.	31	5	5,400	2
		16	8	800	1			32	5	550	1
		18	7	1,300	1		14 E.	11	4	2,800	1
		19	7	500	1			14	4	840	1
		25	11	1,800	2		15 E.	31	3	790	1
		26	11	2,300	[illegible]	21 N.	12 E.	11	7	5,600	2
		27	4	580	1			12	4	980	3
		28	4	400	2			13	10	4,700	5
		35	6	900	6			14	11	6,400	2
	17 E.	18	11	3,000	1			25	3	1,600	4
		20	10	1,100	1			36	5	2,000	2
25 N.	12 E.	1	3	1,300	1		13 E.	5	6	3,600	4
		11	3	1,200	3			6	5	2,500	2
		12	4	400	3			7	7	2,600	3
		23	12	3,600	1			8	6	7,400	1
	13 E.	1	6	900	4			9	6	3,700	1
		2	4	1,100	1			16	9	1,600	1
		3	4	150	2			17	7	4,800	5
		4	7	940	3			18	8	4,300	5
		5	4	1,000	2			19	6	3,000	4
		11	3	1,400	1			20	5	6,400	4
		13	8	1,050	2			25	4	2,200	1
		14	4	200	1			30	4	820	1
		26	6	180	1			32	12	7,300	1
		34	4	80	2			33	11	5,600	2
		35	9	860	3	20 N.	12 E.	13	4	1,300	1
	14 E.	1	5	3,200	2		13 E.	5	4	300	1
		2	5	2,100	2			18	8	7,100	3
		6	8	1,500	3		16 E.	33	3	1,100	1
		7	10	2,500	2	19 N.	10 E.	8	7	1,200	1
		11	3	460	1			11	1	220	1
		13	4	2,000	2		11 E.	25	3	1,100	1
		14	5	500	1			36	1	450	1
		24	2	900	2		12 E.	16	2	16	1
	15 E.	19	3	70	1			18	2	1,300	1
		30	4	280	1			29	3	18	1
	16 E.	1	8	1,100	2			32	3	180	1
		2	9	870	2		13 E.	9	2	440	1
		5	4	630	1			16	4	650	1
		9	3	260	1			30	4	900	1
		11	10	4,600	1			31	3	570	1
		13	7	350	1		16 E.	3	3	400	1
		22	5	360	1			4	3	390	1
		24	11	2,200	3	18 N.	7 E.	5	4	10,300	2
		25	9	820	3			8	3	3,000	1
		36	9	1,400	3			9	2	8,700	2

TABLE 3.—*Average total production per acre of leases, etc.*—Continued.

Township.	Range.	Section.	Approximate average age.	Average total production per acre.	Number of leases used in determining average.	Township.	Range.	Section.	Approximate average age.	Average total production per acre.	Number of leases used in determining average.
			Years.	*Barrels.*					*Years.*	*Barrels.*	
18 N.	7 E.	15	4	3,000	2	17 N.	10 E.	24	3	380	1
		16	3	6,500	2			35	1	360	1
		17	3	4,800	1		11 E.	7	5	930	1
		20	4	2,800	3			10	3	400	2
		21	2	500	1			11	3	640	3
		22	3	500	2			14	4	180	1
		28	4	600	2			26	3	110	1
		29	5	2,000	2		12 E.	1	4	520	1
		30	5	2,000	2			3	7	800	1
		31	4	2,500	2			4	1	230	1
		32	5	2,200	2			5	9	3,400	1
		34	3	3,700	2			7	10	9,800	3
	10 E.	35	3	60	1			12	5	1,600	1
	11 E.	1	6	7,100	4			20	10	9,600	1
		7	3	2,700	1			21	11	8,600	2
		8	3	1,700	4			27	1	3,000	1
		9	3	1,000	1		13 E.	9	2	380	2
		12	6	5,900	5			22	1	4,200	1
		13	7	5,100	3			28	1	2,000	1
		14	7	3,400	2		14 E.	27	1	1,300	1
		16	2	4,000	1			33	1	4,200	1
		17	2	2,100	2			34	1	2,000	1
		21	4	3,500	2			35	1	860	2
		23	7	2,300	2		15 E.	5	1	1,400	1
	12 E.	6	7	1,800	1			7	1	310	1
		7	4	720	3			12	3	1,300	1
		9	3	3,100	2		16 E.	7	1	880	1
		12	3	1,200	1	16 N.	7 E.	3	1	4,200	3
		15	1	900	3			4	1	7,000	3
		16	1	930	1			9	2	1,200	1
		17	7	2,500	2		10 E.	2	3	4,500	1
		18	8	4,000	2		11 E.	5	3	1,100	3
		19	5	3,300	2			8	2	95	1
		20	8	4,800	6			9	2	430	1
		21	7	2,400	1			10	4	900	1
		27	9	3,400	2		12 E.	2	3	1,500	1
		28	8	4,300	2			4	1	170	1
		30	6	590	1			5	3	750	2
		31	10	10,370	1		13 E.	10	3	140	1
		32	5	2,750	1			11	4	2,300	1
		33	9	2,200	1			26	4	1,500	1
		34	9	3,300	3			27	3	970	1
		36	5	220	1			35	4	790	2
	13 E.	4	4	740	1		14 E.	18	4	1,100	1
		7	6	2,500	1		15 E.	5	2	3,900	2
		17	3	980	1	15 N.	12 E.	35	7	3,000	1
		18	5	2,300	1		13 E.	23	1	80	1
		20	3	200	1		14 E.	2	1	1,900	1
		30	4	7,700	1			14	2	1,500	1
	14 E.	25	3	600	1			15	1	1,900	1
		26	2	290	1			16	2	1,100	1
		36	2	90	2			23	4	2,000	1
	15 E.	29	1	3,400	1			28	7	1,600	1
17 N.	7 E.	3	4	10,500	2			30	5	350	1
		4	3	11,700	3	14 N.	12 E.	3	7	5,400	1
		5	5	18,200	4			4	1	400	1
		6	4	8,400	3			9	7	26,000	1
		7	4	700	2			11	4	1,700	1
		8	4	11,200	5			12	5	2,400	1
		9	3	14,900	4			13	4	2,200	2
		10	3	43,500	2		13 E.	2	2	300	1
		11	3	10,500	3			9	1	200	1
		15	2	600	1			18	6	1,700	3
		16	3	16,900	3		17 E.	12	7	2,800	3
		17	4	2,000	3			13	9	2,000	1
		18	4	1,100	1		18 E.	1	1	200	1
		20	3	1,500	3			7	8	1,000	2
		21	3	1,800	2	13 N.	11 E.	26	3	450	1
		22	3	3,200	2		13 E.	12	4	4,900	2
		27	1	3,300	3			14	3	570	1
		33	1	5,100	2			15	5	1,100	1
		34	1	1,700	2			18	1	3,200	1

TABLE 3.—*Average total production per acre of leases, etc.*—Continued.

Township.	Range.	Section.	Approximate average age.	Average total production per acre.	Number of leases used in determining average.	Township.	Range.	Section.	Approximate average age.	Average total production per acre.	Number of leases used in determining average.
			Years.	*Barrels.*					*Years.*	*Barrels.*	
13 N.	13 E.	27	3	700	1	13 N.	16 E.	21	6	2,100	2
		29	3	900	1	12 N.	12 E.	9	4	1,600	1
	14 E.	3	3	200	1			10	4	500	1
		4	2	160	2			30	4	1,200	1
		13	3	2,700	1		13 E.	19	2	200	1
		18	1	1,300	1	11 N.	14 E.	6	3	6,400	1
		24	4	1,250	1	4 S.	3 W.	3	2	1,300	2
		25	4	1,450	2			4	3	6,500	4
		27	4	1,100	2			6	3	20,500	5
		28	10	2,600	2			9	3	1,700	1
		29	10	10,800	1			10	2	1,950	4
		32	10	7,000	1			15	1	1,500	5
		33	3	1,600	1	3 S.	3 W.	30	1	8,000	1
		36	6	1,300	1			31	3	12,000	2
	15 E.	7	3	600	1			32	3	6,100	2
		18	2	240	1						

BIRD CREEK-FLATROCK AREA.

GENERAL STATEMENT.

The Bird Creek-Flatrock area (Pl. I, p. 106) lies a few miles south of the southern end of the Bartlesville field, and is similar to it in depth of sand and in geologic conditions. Approximately 10,000 acres have been drilled. Most of the oil is obtained from the Bartlesville sand, although some comes from deeper sands, such as the Burgess and the Tucker. For many wells the average daily production per well the first year is about 30 barrels, the high and low limits being 125 and 3 barrels.

APPRAISAL CURVE.

Figure 33 shows the appraisal curve of this district. Because of the curves being based on data insufficient for locating the limiting curve accurately, the ultimate production estimates made by its use should carry a liberal factor of safety.

COMPOSITE DECLINE CURVE.

The curve showing the average decline in the production of wells in the area is printed as figure 34. It will be seen that from an average of 38 properties the second year's average daily production per well is an average of 60 per cent of the first year's average daily production. During the third year the average well makes about 37 per cent of the daily production of the first year. Although the curve shows the second year's production to be greater than that of the

other pools in Oklahoma the decline during the subsequent years is more rapid. However, this, as well as many other composite curves presented, are based on the records of only a few properties.

ESTIMATING CHART.

Figure 35 shows the chart, prepared from the appraisal curve, for use in making rapid estimates of the future output of producing tracts, as described on pages 76–80. The chart may be used for wells making 10 to 80 barrels daily.

GENERALIZED DECLINE CURVE.

On account of the duplication of work involved, it was not thought necessary to prepare a generalized decline curve for this area, especially as the data were not so complete as in other pools, for the reader, if he finds such curves will be of value, should have no difficulty in preparing them himself.

SAND THICKNESS AND ACREAGE PER WELL.

Figure 36 shows the curves determined by plotting the average sand thickness under each property against the ultimate cumulative percentage of that property, and also by plotting average acreage per well on each lease against its ultimate cumulative percentage. It should be noted that the limits of productivity as determined by the average thickness of sand are rather narrow. For instance, a well producing from a sand 24 feet thick will ultimately yield a minimum of 1.5 times and a maximum of 3.0 times its first year's output.

On account of the uniform depth of the wells on the properties in this area and because of the lack of records, it was not feasible to construct a curve showing the variation of ultimate cumulative percentages with the depth of the productive sand.

TOTAL PRODUCTION DATA.

Table 3 shows the average total production per acre of the properties on different sections.

THE NOWATA FIELD.

GENERAL STATEMENT.

The Nowata field (Pl. I, p. 106) is the shallowest in Oklahoma, for the productive sand in parts of the field lies 300 to 800 feet below the surface. Consequently most of the wells are drilled by portable
in a few days. The drilled area comprises about 48,000 acres.
ıction has declined so that the present average daily output per

well is very low. Statistics prepared by the author in 1916 showed that during 1915 out of 4,500 producing wells on Indian land in the Cherokee Nation 1,079, or 24 per cent, averaged less than 1 barrel daily; 3,253, or 72 per cent, averaged between 1 and 10 barrels daily;

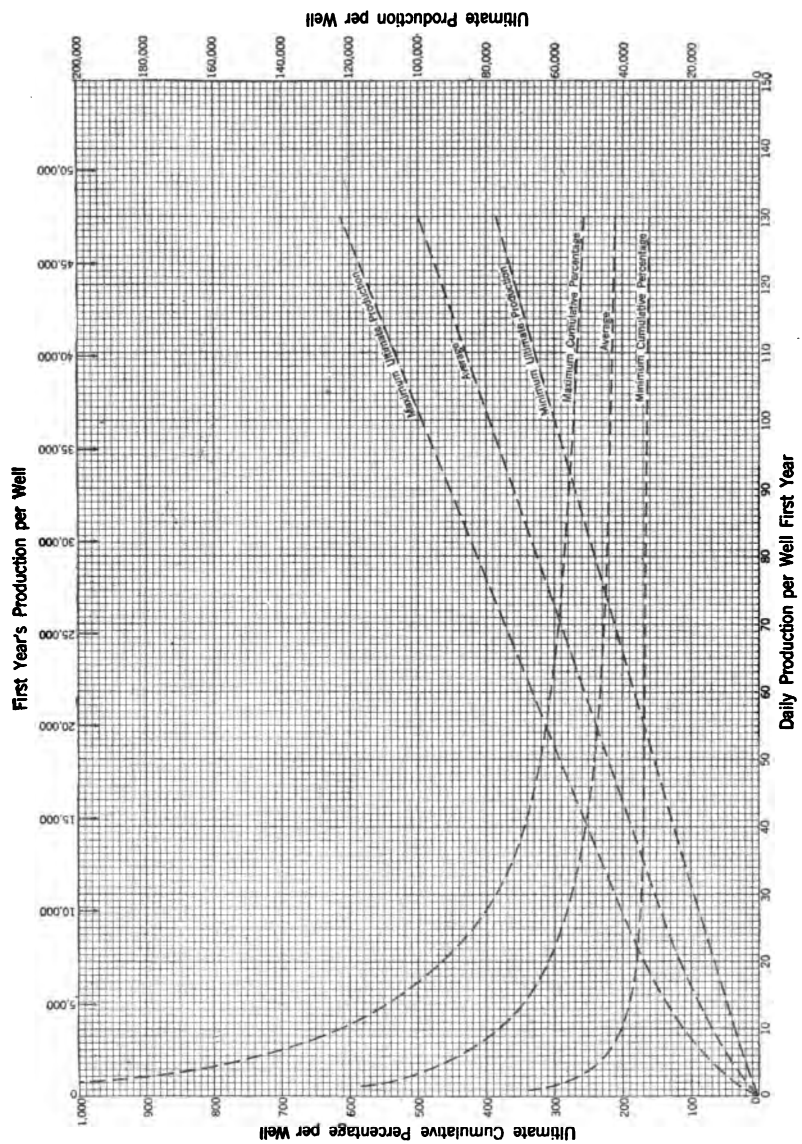


FIGURE 33.—Appraisal curve for the Bird Creek-Flatrock area, Okla.

and 168, or approximately 4 per cent, averaged between 10 and 100 barrels daily. The wells on no property in the Cherokee Nation were averaging more than 100 barrels daily. These figures of output, of course, include only the Indian acreage, which lies in all the fields in

the Cherokee Nation, but may be taken as a fairly trustworthy index of the output of the rest of the drilled acreage there. The restricted Indian land that was producing oil at that time comprised between

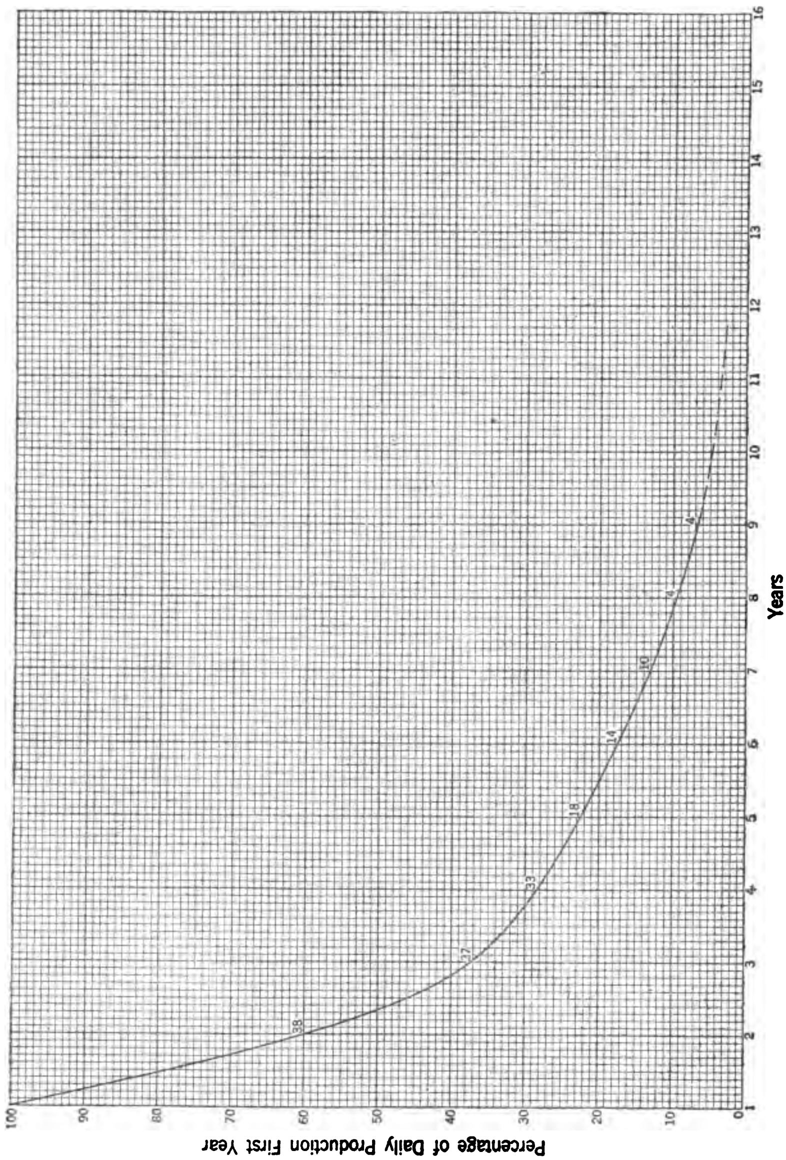


FIGURE 34.—Composite decline curve for the Bird Creek-Flatrock area, Okla.

one-fourth and one-fifth of the total productive oil land within the nation.

Inasmuch as other pools, such as the Bartlesville, were included in these calculations, the information can not be confined to the

Nowata field alone, but it is safe to say, because of the shallow depth of the productive sand in the Nowata field, that the average

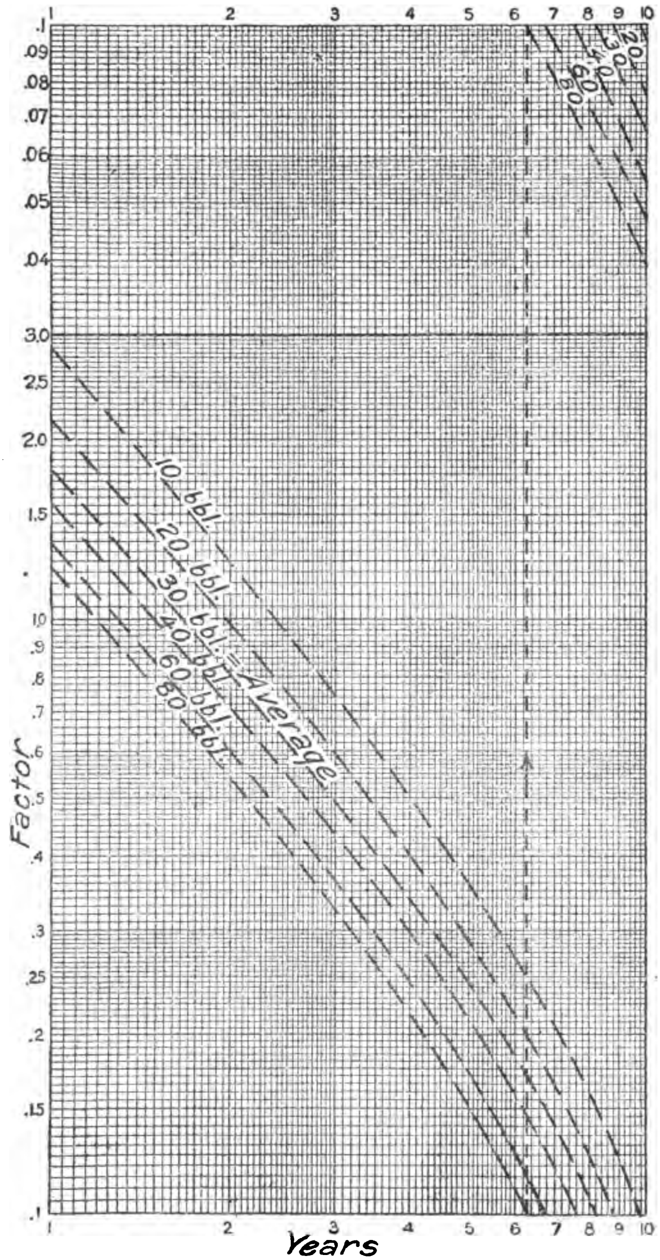


FIGURE 35.—Estimating chart for the Bird Creek-Flatrock area, Okla.

output per well is considerably below that determined to be the average for the wells on the restricted land in the whole Cherokee

Nation. Two principal sands are producing; the first, the Oswego, lies about 300 feet below the surface and is equivalent to the Oswego limestone. The Bartlesville sand lies below and is equivalent to the sand of the same name from which the bulk of the oil in Oklahoma

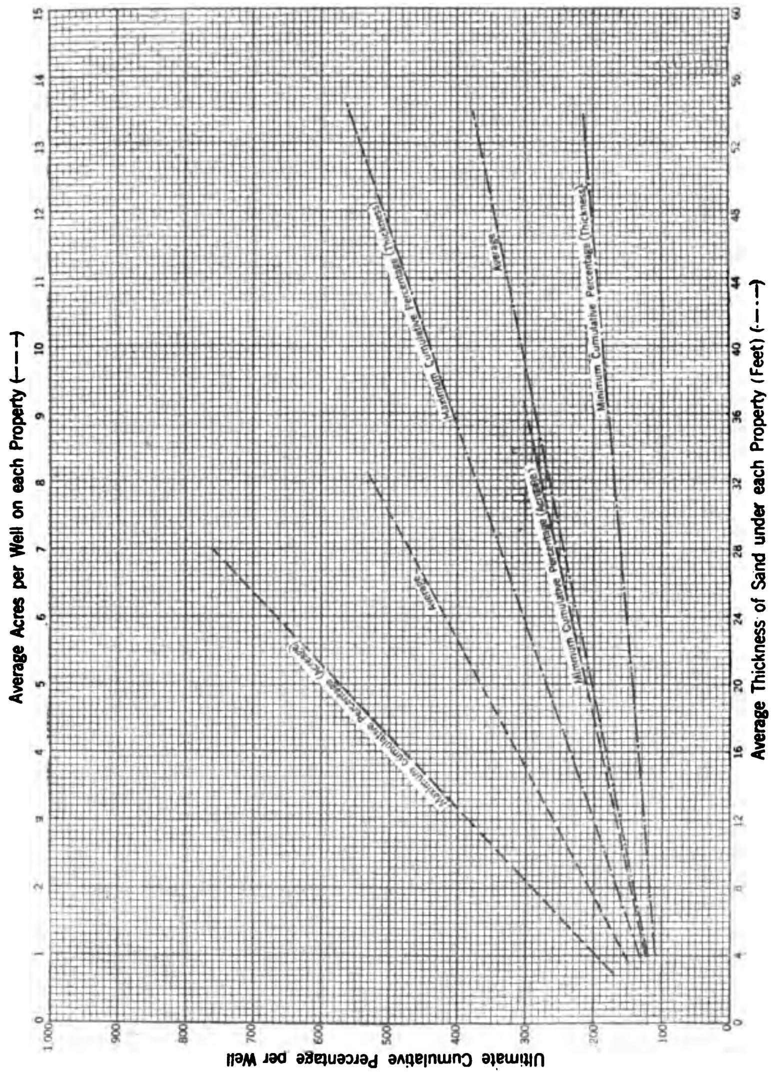


FIGURE 36.—Relation of average thickness of sand underlying some of the properties and the average acreage per well in the Bird Creek-Flatrock area, Okla., to the ultimate cumulative percentages of the wells on the properties.

is produced. The average daily production of wells the first year in this field is about 19 barrels, with high and low limits of 1 to 118 barrels.

The range of thickness of the productive sand is shown in figure 37, which was constructed by plotting the average thickness of the

sand under each property against the ultimate cumulative percentage of that property. The spacing of the wells is close, presumably because of the low gas pressure, and undoubtedly is economically

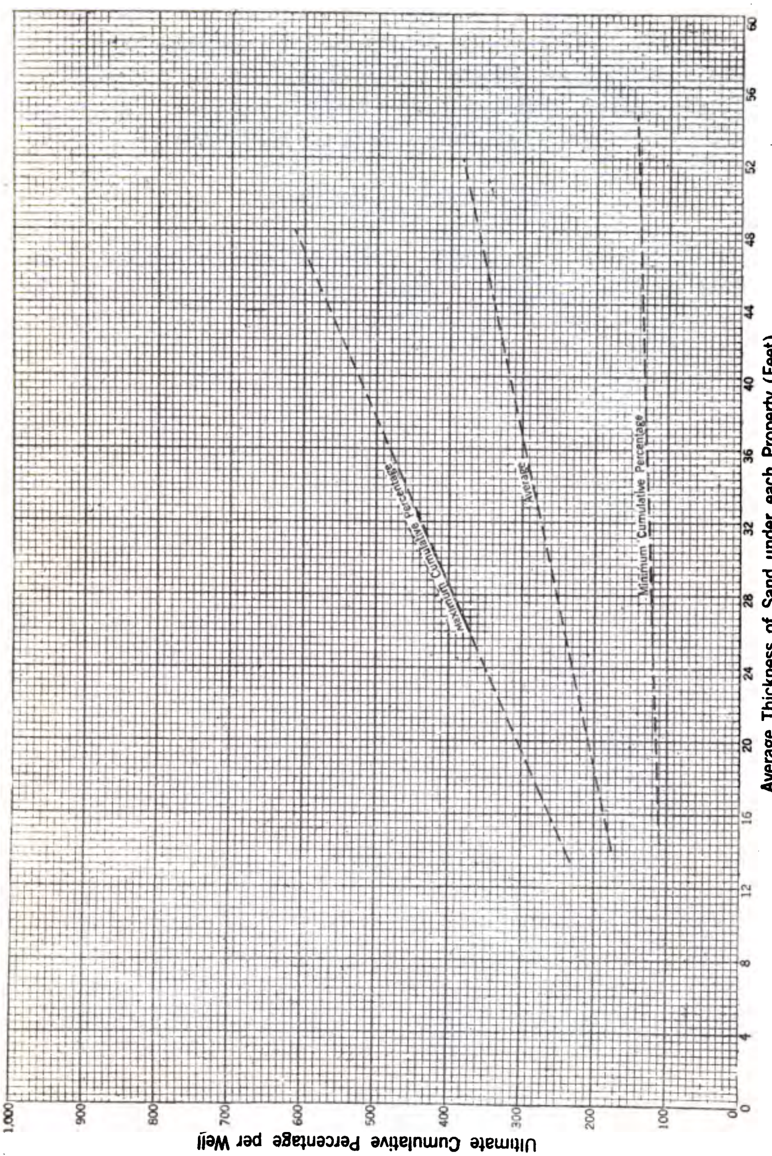


FIGURE 37.—Relation of the average thickness of sand underlying some of the properties in the Nowata field, Okla., to the ultimate cumulative percentage of the wells on the properties.

possible because of the small cost of drilling. Many 10-acre tracts have as many as five wells, and the average spacing is probably about three to five acres per well.

APPRAISAL CURVE.

Lewis and Beal[a] in a short preliminary paper published the appraisal curve for the Nowata field (fig. 38). This curve is based on the action of 69 regularly operated properties on which are a total of about 700 wells. The limits determined by plotting the ultimate cumulative percentages of these properties are very narrow, especially for the large wells, so that estimates of future and ultimate production made from this curve may be used with confidence.

COMPOSITE DECLINE CURVE.

Figure 39 gives the composite decline curve constructed from the properties in this district. Actual records were obtained for 11 years, so that the construction of this curve is a matter of certainty. During the first two years 68 properties were available for the average, but this number fell off, so that during the eleventh year only four properties were used. It is noteworthy that the average well in this field yields during its second year one-half the output of its first year, and during the third year yields only 30 per cent of its first year's output.

ESTIMATING CHART.

The chart prepared for making rapid estimates of future production of developed properties is shown in figure 40. These curves are somewhat generalized from those actually determined by calculations made from the appraisal curve, as outlined on pages 76–80. The reader is again warned that these charts are only for making hasty estimates; the appraisal curve itself should be used for more accurate estimates.

GENERALIZED DECLINE CURVE.

Figure 41, which shows the generalized decline curve, brings out the narrow limits of the actual decline of the type curves. The duration of the production of most of the wells used in constructing the generalized decline curve permits considerable reliance to be put on estimates made from this cause.

DATA ON THICKNESS OF SANDS.

Figure 37, already mentioned, shows the limitations of productiveness as determined by the thickness of the producing sand in this field.

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[a] Lewis, J. O., and Beal, C. H., Some new methods for estimating the future production of oil wells: Am. Inst. Min. Eng. Bull. 134, February, 1918, pp. 477–504.

One can see by referring to this figure that the minimum ultimate production of the property underlain by a productive sand 28 feet

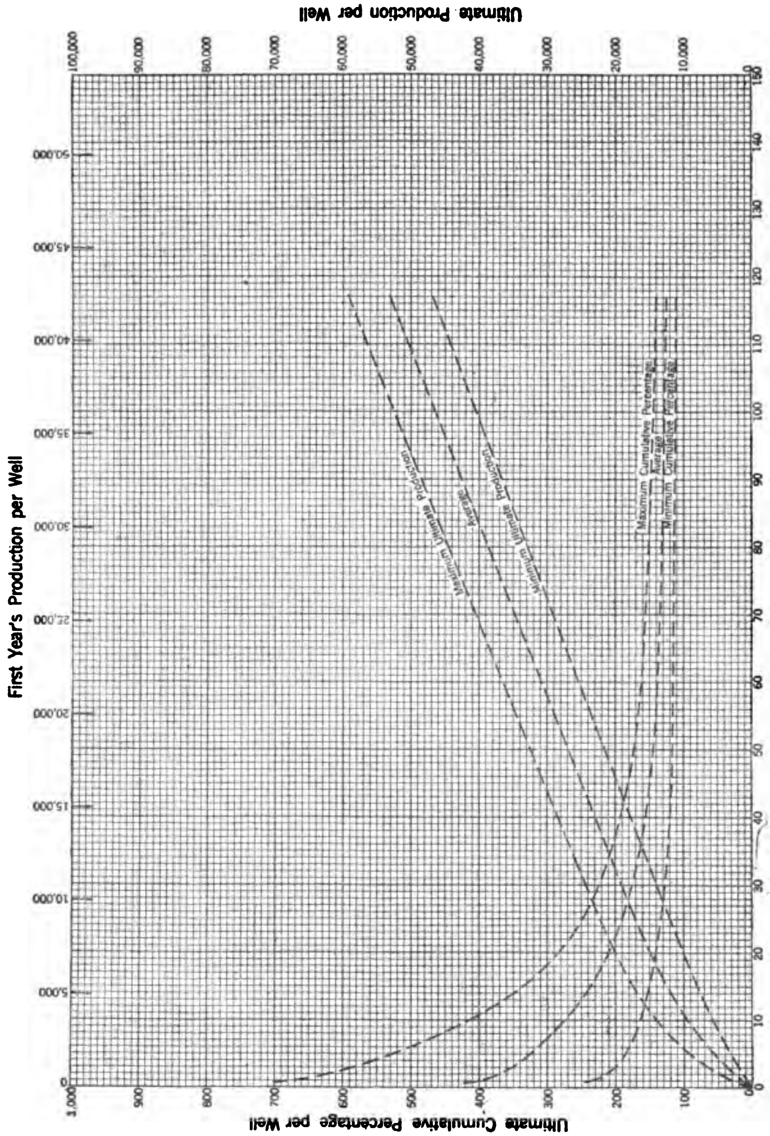


FIGURE 38.—Appraisal curve for the Nowata field, Okla.

thick is about 1.2 times and the maximum ultimate production of the same property is about 3.9 times its first year's output. Although the limits thus determined are by no means narrow, nevertheless they

should often be of considerable aid in making closer estimates of future and ultimate output.

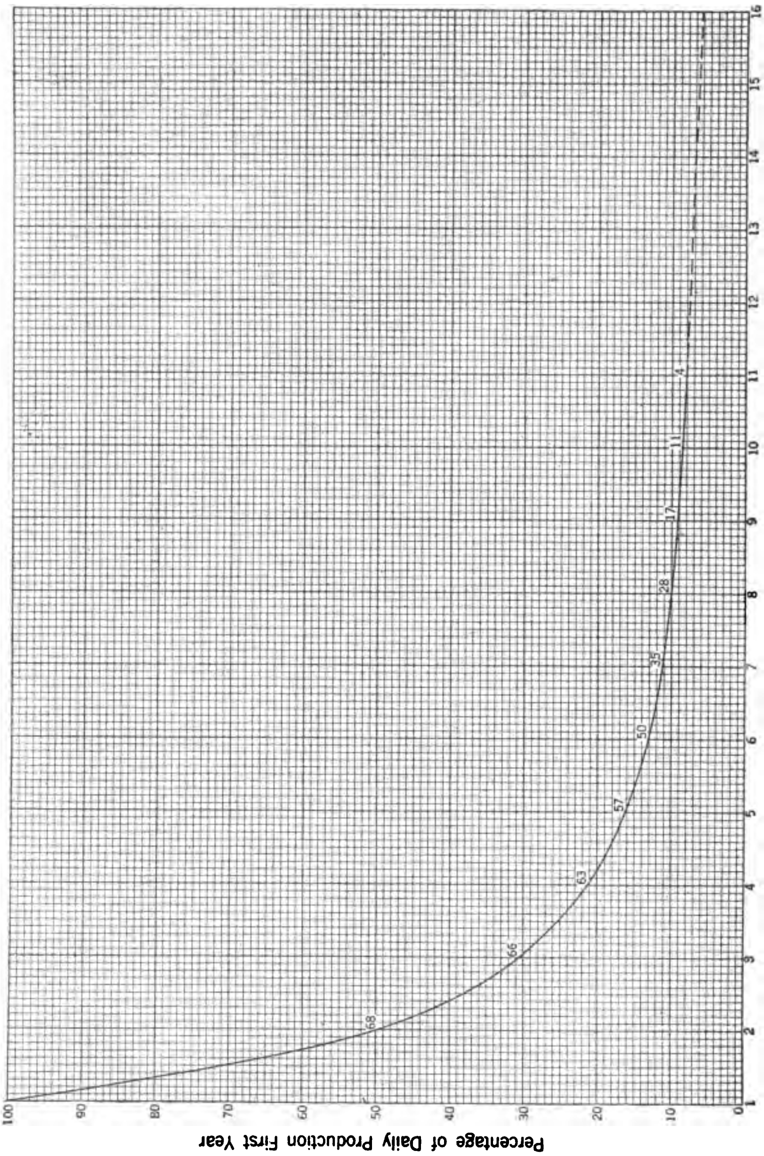


FIGURE 39.—Composite decline curve for the Nowata field, Okla.

ACREAGE OF WELLS.

Figure 42 shows the curves derived by plotting the average acres per well of different properties against the ultimate cumulative per-

centage of each property. The limits determined by this method of plotting were not so narrow as those shown in figure 37, although

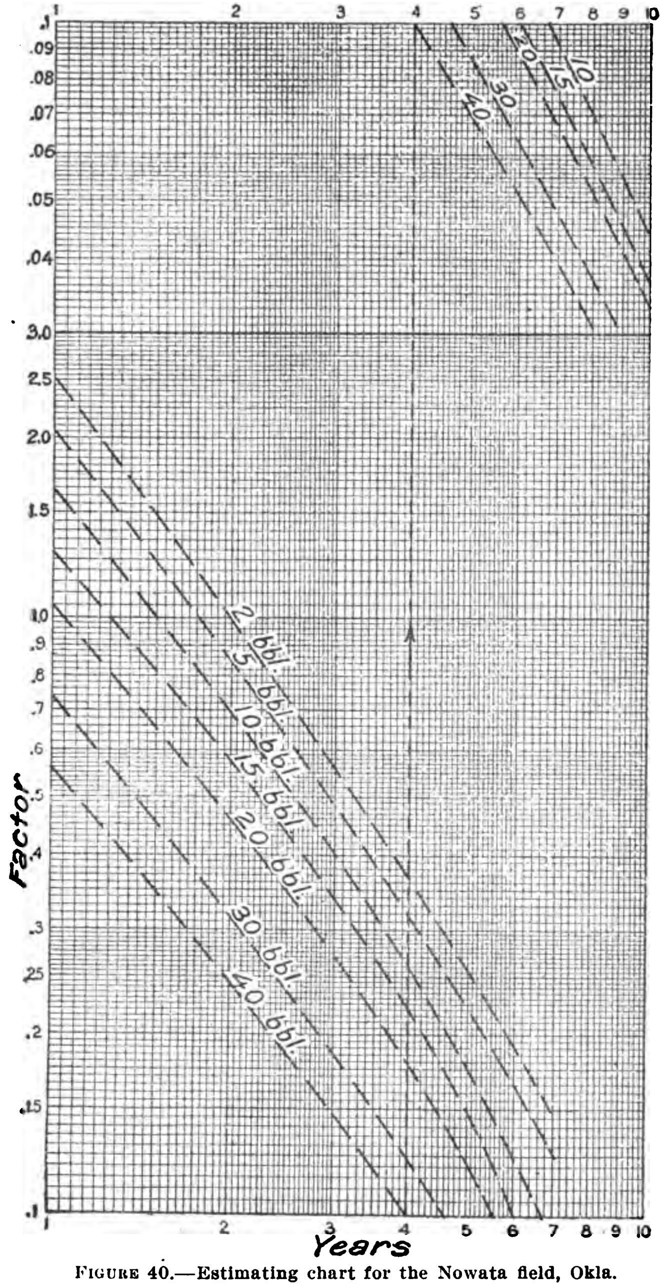


FIGURE 40.—Estimating chart for the Nowata field, Okla.

they undoubtedly will prove of aid in making closer estimates of future and ultimate production.

COMPARISON OF THE NOWATA FIELD WITH THE OSAGE DISTRICT.

As was pointed out in a paper by Lewis and Beal,[a] the appraisal curves of the Nowata and Osage fields differ considerably, and the

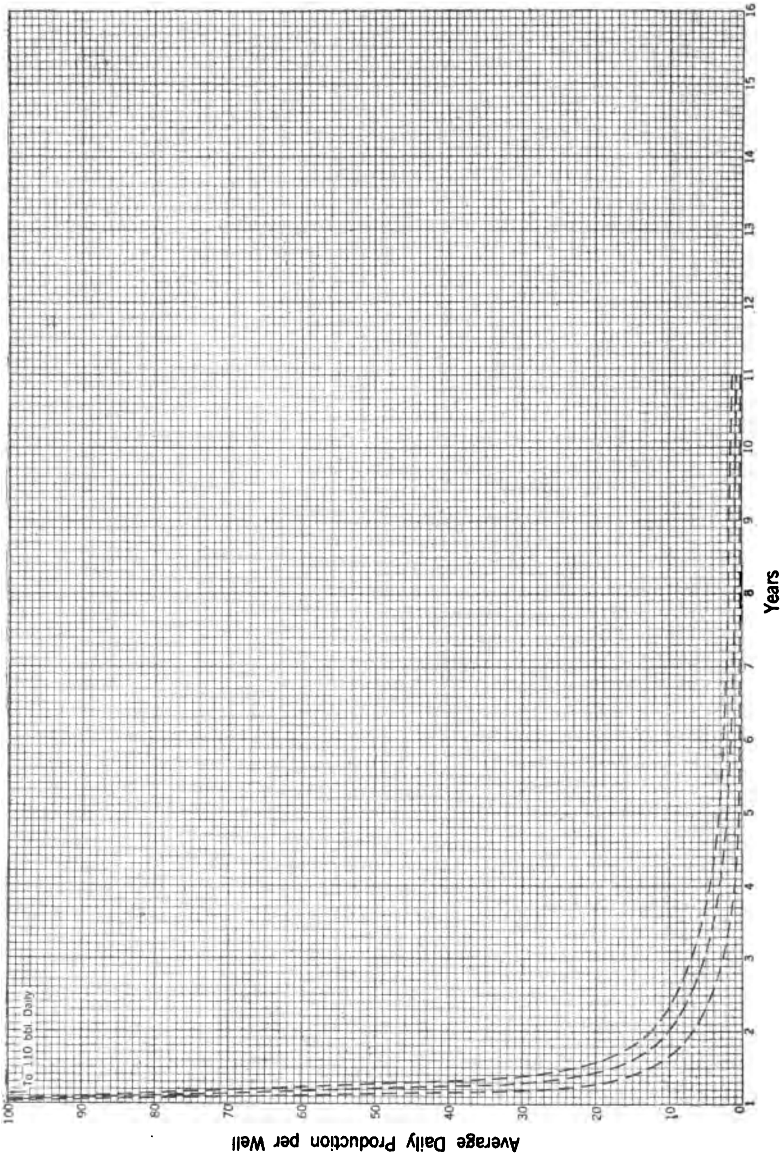


FIGURE 41.—Generalized decline curves for the Nowata field, Okla. Production figures are in barrels.

Nowata field has much narrower limits for forecasting the probable future production from the first year's production. The *maximum*

[a] Work cited, p. 490.

cumulative percentages of wells of 30 barrels in the Nowata field is about 225 per cent, which is about the same as the *minimum* cumula-

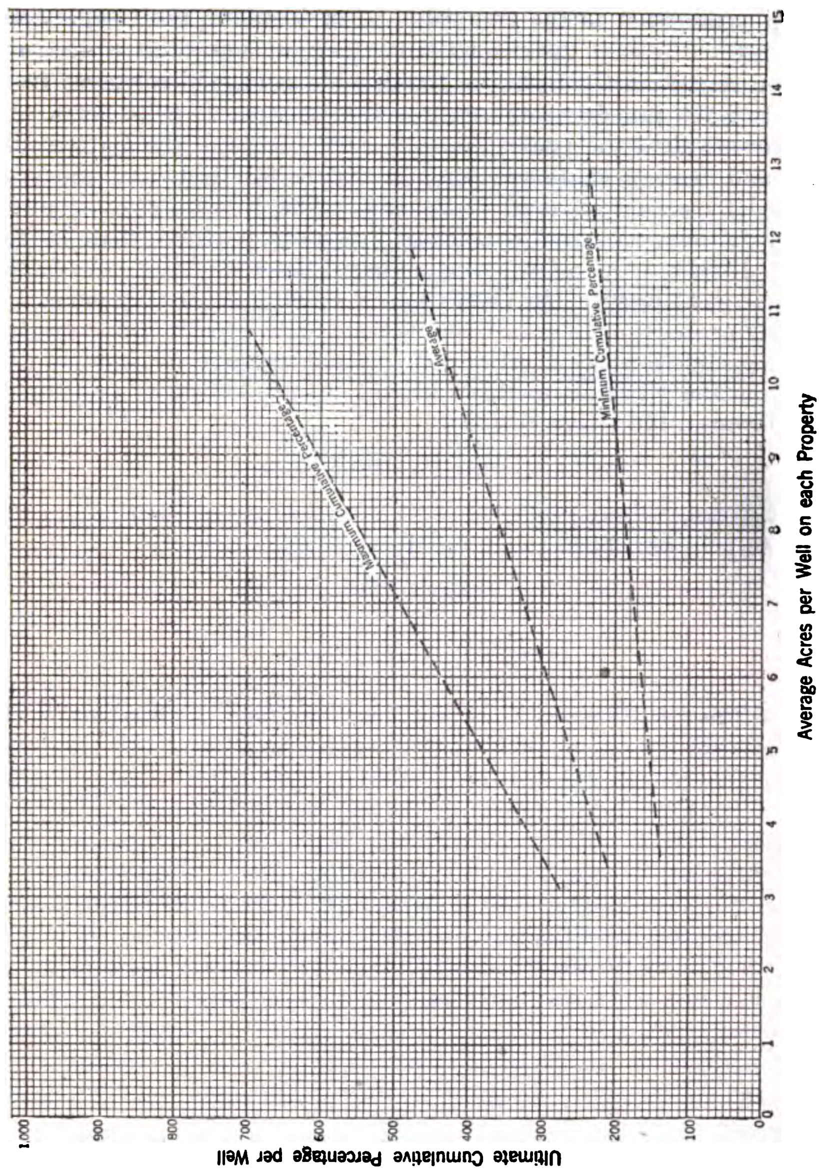


FIGURE 42.—Relation of average acreage pe... ...nate cumulative percentages of wells in the Nowata field, Okla.

tive percentage of a well of the same size in the Osage Reservation. That is, a well of the same size in the Osage Nation will ultimately produce at least 2¼ times the first year's output, whereas one in the

Nowata field will make not more than 2¼ times the first year's production.

These differences may be attributed to different conditions governing production in the two fields. For instance, the Osage wells are scattered over a district 60 miles long and 20 miles wide; production comes mostly from the Bartlesville sand, which ranges from 1,500 to 2,500 feet deep; and each well is allotted 10 to 12 acres. In the Nowata field the production comes mostly from the Bartlesville sand and from a shallower sand at 300 to 800 feet, and the area drained by each well is 2½ to 5 acres. The Nowata field is practically in one pool and conditions are more uniform than in the Osage district. One of the underlying differences is, of course, the original gas pressure (in Oklahoma, the original gas pressures are roughly proportionate to the well depths); this greatly influences the initial production and thereby controls the ultimate production. In addition, the oil sands in the Nowata field are known to be thinner than those in the Osage district.

TOTAL AND ULTIMATE PRODUCTION.

The average total production per acre for several sections in the Nowata field are obtainable from Table 3, page 118.

GLENN POOL.

GENERAL STATEMENT.

The Glenn pool was discovered in 1906, and until the discovery of the Cushing pool was the most productive oil field in Oklahoma. Its area is approximately 19,000 acres, which happens to be approximately the same as that of the productive area of the Cushing field. Plate I (p. 106) and figure 50 (p. 147) show the situation of the pool. The depth of the pool varies with the geological structure and with the stratigraphic position of the producing sand. The Glenn sand, by far the most productive, is considered by some as equivalent to the Bartlesville sand of northeastern Oklahoma.

Because of its being divided into small tracts and because of its productiveness the Glenn pool has been drilled rather closely, that is the acreage per well is smaller than it should be, averaging about five to eight acres, although on some leases each well is allowed about 10 acres.

The average output per well on about 60 properties was 45 barrels daily during the first year, ranging from about 4 barrels to 200 barrels daily. Many of the wells during the first 24 hours were very productive, but declined rapidly, partly on account of the close spacing, so that the actual daily production during the first year does not average high.

One of the most puzzling characteristics of the Glenn pool is its structure, several poorly developed anticlines plunging west; but

the contours showing the structure are hardly more than wavy lines, indicating that the strike is but little interrupted by folds. Plate I shows the generalized structure of the Fort Scott limestone of northeastern Oklahoma. The structure contours of this formation in and adjacent to the Glenn pool were determined by Smith.[a] The Fort Scott limestone lies above the productive oil sands, so that the structure contours in Plate I may not represent the structure of the deeper beds if there is an unconformity between them and the Fort Scott limestone, or if the underlying productive formations are not similarly folded; in fact, this possible lack of conformity may be one of the causes of the apparent anomaly of a phenomenal output from a slightly warped monocline. However, the lenticularity of the productive formations in the Glenn pool may greatly influence the production.

The curves following are based on data furnished by 60 representative properties in the Glenn pool.

APPRAISAL CURVE.

The appraisal curve of the Glenn pool is shown in figure 43. The trustworthiness of the information on which these curves are based should render estimates of future and ultimate production very trustworthy.

COMPOSITE DECLINE CURVE.

Figure 44 gives the average yearly decline of many properties in the Glenn pool. A few of the records extended over a period of 11 years, so that the accurate projection of the average curve should not be difficult. However, the limitations in using this curve should be remembered, for it is based upon the average performance of many wells on about 60 properties. Some of these wells may have been gushers that yielded large quantities of oil the first year, and others may have been small "pumpers." Other average decline curves, showing the decline of particular groups of properties, are shown in figure 3 (p. 22).

ESTIMATING CHART.

Figure 45 shows the chart, prepared from the appraisal curve, for use in making rapid estimates of the future output of producing wells. On account of the size of the wells in the Glenn pool and the rapidity with which some of them decline, the curves shown in figure 45 are not so regular as those shown in other similar charts.

[a] Smith, C. D., The Gleen oil and gas pool and vicinity, Oklahoma: U. S. Geol. Survey Bull. 541, pt. 2, 1912, pp. 34–48.

GENERALIZED DECLINE CURVE.

The generalized decline curves of wells that produce along maximum, average, and minimum curves are shown by figure 46.

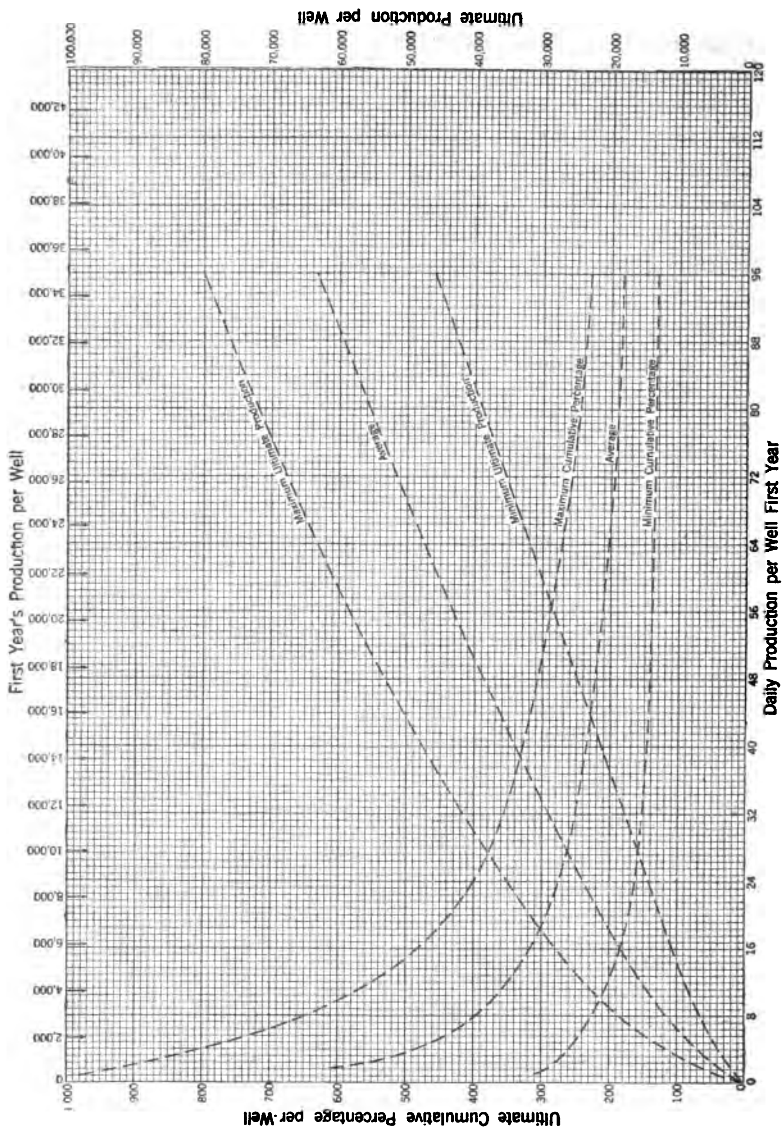


FIGURE 43.—Appraisal curve for the Glenn pool, Okla. Production figures are in barrels.

RELATION OF SPACING OF WELLS TO ULTIMATE CUMULATIVE PERCENTAGES.

Figure 47 gives the determined limits of ultimate cumulative percentages determined by plotting the average acreage per well against the ultimate cumulative percentage per well of different properties.

The use of these curves in narrowing the limits of estimates of future and ultimate production has been explained.

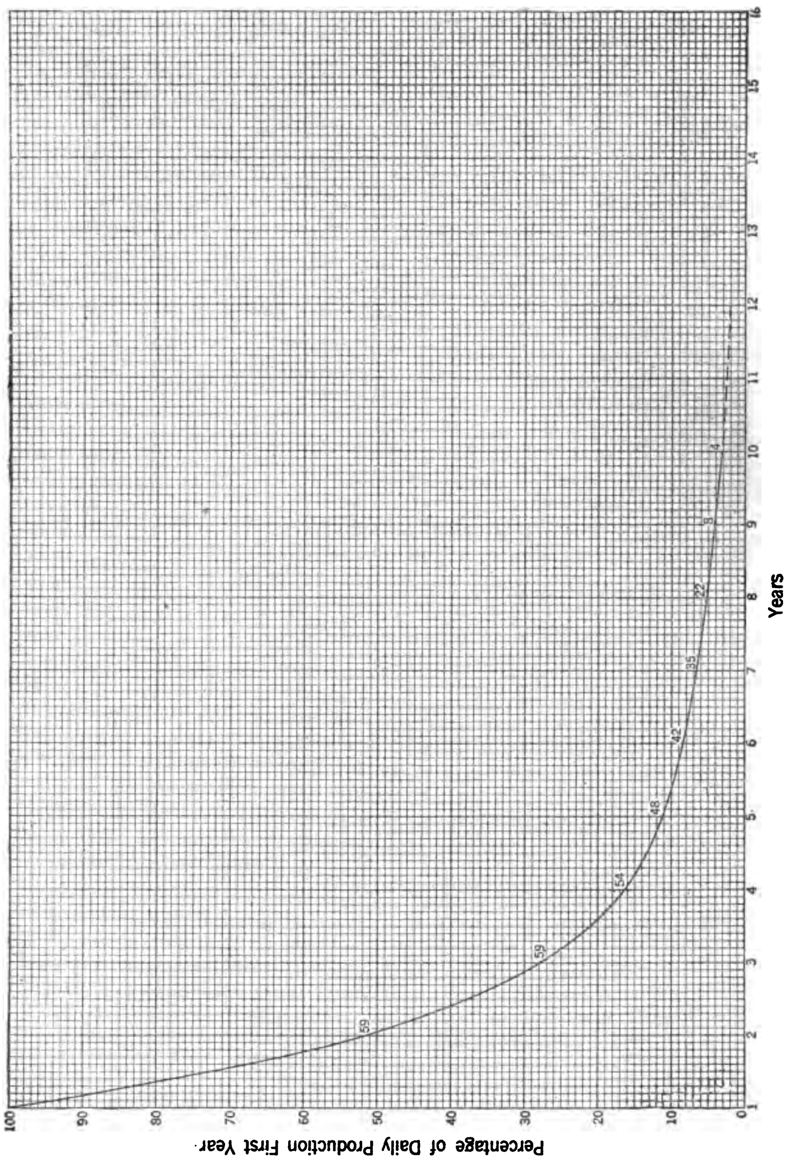


FIGURE 44.—Composite decline curve for the Glenn pool, Okla.

DATA ON TOTAL AND ULTIMATE PRODUCTION.

The total marketed production for the Glenn pool, according to statistics collected by the United States Geological Survey, is approximately 140,000,000 barrels, and the drilled area includes about

19,000 acres. Hence the average production per acre is 7,000 to 7,500 barrels. If the assumed thickness of the productive sand is

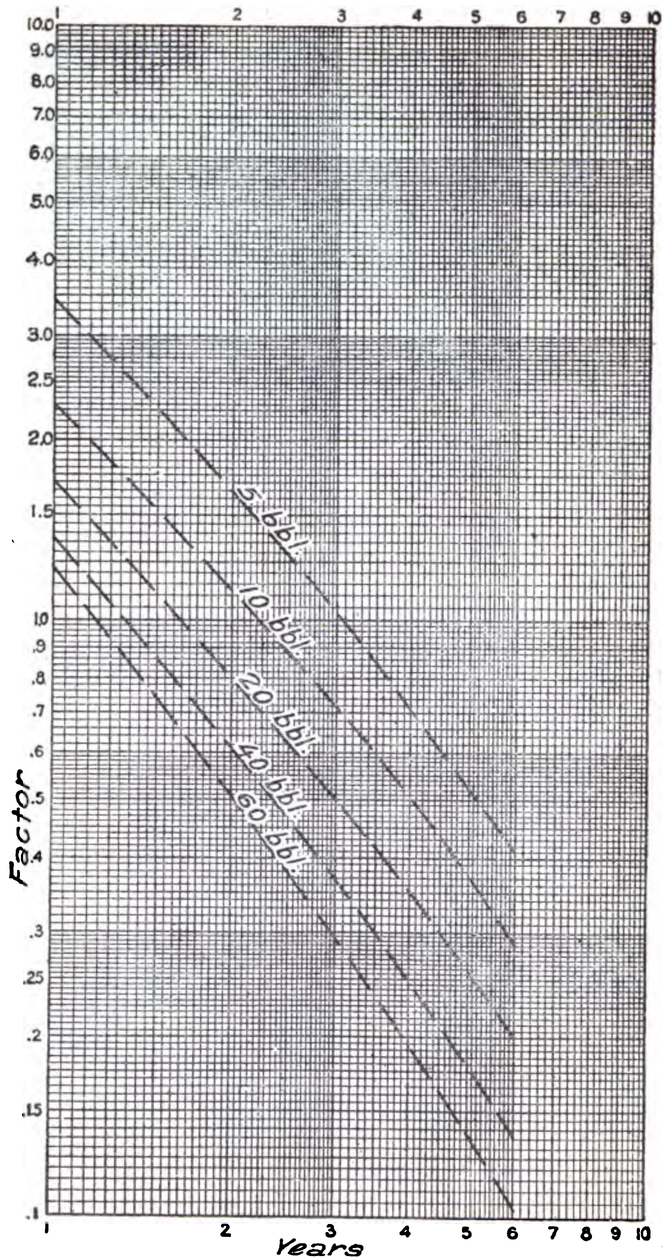


FIGURE 45.—Estimating chart for the Glenn pool, Okla.

approximately 30 feet, the average production per acre-foot is about 245 barrels. This last estimate can not be trusted, however, because

of the difficulty in obtaining accurate information on the thickness of the sand that produces oil. Table 3 shows the total production to date for many of the sections in the Glenn pool, and Table 4

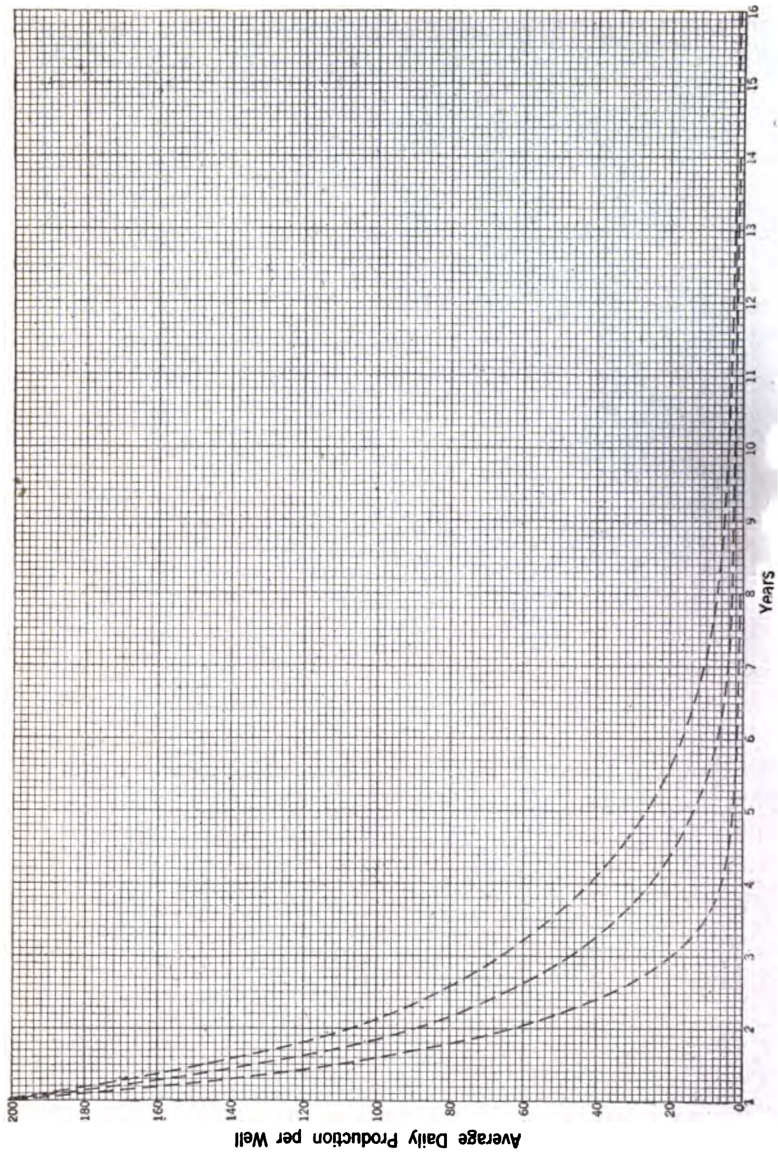


FIGURE 46.—Curves for the Glenn pool, Okla.

following gives the production per acre, the sand producing, and the estimated production per acre-foot on several individual leases selected at random.

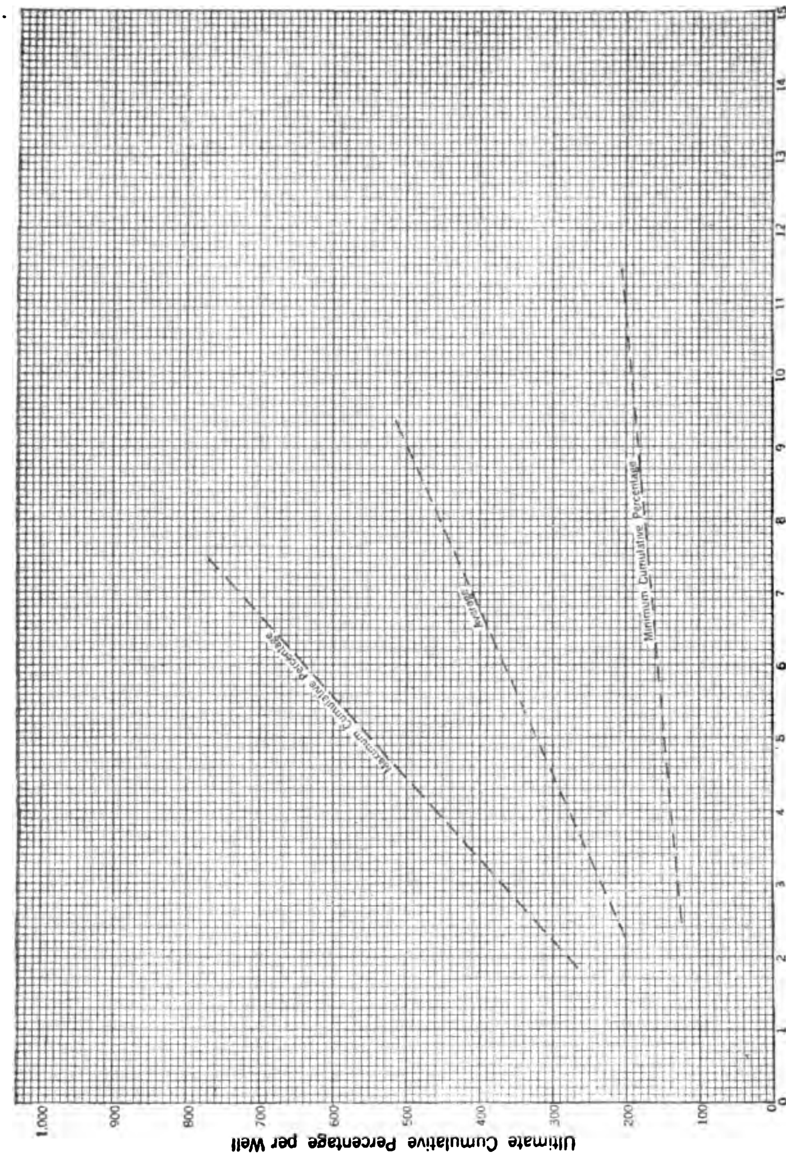


FIGURE 47.—Relation of average acreage per well to the ultimate cumulative percentages of wells in the Glenn pool, Okla.

TABLE 4.—*Production per acre, estimated output per acre-foot, and productive sand on several leases selected at random in the Glenn pool, Oklahoma.*

Section.	Township N.	Range E.	Sand producing.	Total production per acre.	Total production per acre-foot.	Section.	Township N.	Range E.	Sand producing.	Total production per acre.	Total production per acre-foot.
27	18	12	Glenn	2,450	90	30	18	13	(?)	960	(?)
20	17	12	....do	9,650	270	16	19	13	(?)	650	(?)
27	18	12	....do	2,000	75	1	18	11	Glenn	8,900	390
7	17	12	....do	1,130	32	5-31	17-18	12	....do	9,950	270
9	17	13	Dutcher	738	50	7	17	12	....do	14,500	416
14	18	11	Glenn	2,000	91	7	18	12	....do	640	10
7	18	12	....do	1,400	41	6	18	12	....do	1,780	75
12	18	11	Glenn and Taneha.	680	18	34	18	12	....do	2,350	66
						10-28	18	12	....do	4,950	141
34	18	12	Glenn	870	24	21	18	12	....do	2,400	160
23	18	11	....do	2,600	130	12-20	18	12	....do	3,800	62
21	18	11	....do	2,900	100	17-20	18	12	....do	8,650	190
34	18	12	....do	4,000	110	20	18	12	....do	4,000	64
18	18	12	....do	5,700	95	20-34	18	12	....do	5,750	115
18	18	12	....do	1,760	30	33	18	12	....do	2,200	59
5	17	12	....do	3,250	72	34	18	12	....do	3,800	105
13	18	11	Glenn and Taneha.	8,600	107	17	18	12	....do	2,350	78
						20	18	12	....do	4,900	77
1	18	11	....do	750	13	20-21	17	12	....do	7,050	190
13	18	11	....do	2,220	22	1	17	12	....do	5,200	326
13	18	11	Glenn	4,150	58	7	17	12	....do	930	58
17	18	12	....do	2,500	85	12	17	12	Glenn and Taneha.	1,560	52
33-28	18	12	....do	3,800	108						
21	17	12	....do	10,850	285	3	17	12	Glenn	800	26
12	18	11	Glenn and Taneha.	6,250	153	1	18	11	....do	16,250	700
						7	18	12	....do	560	17
8-19	18	12	Glenn	5,400	96	1	18	11	....do	13,200	570
12	18	11	Glenn and Taneha.	6,080	275	14	18	11	....do	4,000	180
						6-36	17-18	12	....do	1,720	57
12	18	11	....do	6,900	345	34-35	19	12	(?)	775	(?)
7	17	12	Glenn	14,500	415	18	18	13	Perryman	1,550	65
4	18	13	....do	740	37	7	18	13	....do	1,700	74

THE CUSHING FIELD.

GENERAL STATEMENT.

The Cushing field lies in the western part of the Creek Na Okla. (Pl. I, p. 106, and fig. 50, p. 147), principally in T. 16 R. 7 E.; T. 17 N., R. 7 E.; T. 18 N., R. 7 E., and in the south part T. 19 N., R. 7 E. Its productive area is about 19,000 acres, and it has produced to date more than 200,000,000 barrels, or an average of about 11,000 barrels per acre.

PRODUCTIVE SANDS.

There are three principal productive sands—the Layton, the Wheeler, and the Bartlesville. The Layton sand ranges in depth from 1,200 to 1,500 feet and is 20 to 100 feet thick, although the latter thickness is not common. The sand is porous and comparatively soft. Approximately 14 square miles of this sand produces oil, and 12 square miles of it originally carried much gas. The Wheeler sand which lies 600 to 900 feet below the Layton, ranges in thickness from 50 to 100 feet, and its lower sandy member is claimed by some to be equivalent to the "Oswego lime" (Fort Scott limestone) of

northeastern Oklahoma and southeastern Kansas. Approximately 11 square miles of the Wheeler sand originally carried oil and 21 square miles produced gas exclusively. The Bartlesville sand lies 350 to 550 feet below the Wheeler and is by far the most productive oil sand in the Cushing field. This sand attains a thickness of 200 feet and is lenticular, its thickest part being in the crest of the dome of the northern part of the field. The total oil and gas producing area of the Bartlesville sand on the main Cushing anticline is about 20 square miles, of which only two square miles originally carried gas alone.

Other sands have produced oil and gas in the Cushing field, but they are not so important as the three mentioned. For instance, the Jones and the Cleveland sands lie between the Layton and the Wheeler. The Skinner sand lies just above the Bartlesville, and the Tucker sand closely underlies the Bartlesville. In some places the wells drilled to the Tucker sand have been extremely productive. Figure 48 shows the generalized columnar section of the formations penetrated by the drill in this field, and also the stratigraphic relations of the oil and gas sands.

In the Cushing field the average spacing of the wells is 6 to 10 acres per well for each sand. The average daily production per well during the first year differs with the sand to which the well is drilled. The average for the Layton sand is 34 barrels for about 100 wells; for the Wheeler sand 53 barrels for nearly 150 wells; and for the Bartlesville sand 208 barrels for about 100 wells. Wells to the Layton sand make initial productions that range from a few barrels to usually not more than 500 or 600 barrels the first 24 hours, although in one locality in the Cushing field wells to the Layton produced the first 24 hours between 500 and 1,000 barrels. The Wheeler sand has been by no means so productive as the Layton or Bartlesville sands, and ordinarily the wells to it have not produced more than 200 to 300 barrels during the first 24 hours. The Bartlesville sand on the crest of one of the domes in the northern part of the field, furnished many wells of an initial daily production between 5,000 and 10,000 barrels, but in the southern part of the field few of the wells drilled into this sand produced more than 3,000 barrels the first 24 hours. The Tucker sand, although less extensive than any others in the area, has furnished some excellent wells, the largest producing during the first 24 hours nearly 15,000 barrels.

GEOLOGIC STRUCTURE.

The general structure of the Cushing field is that of a broad north-south anticline along whose major axis are domes of varying size and importance. The major anticline, one of the largest in the oil

and gas bearing formations in Oklahoma, is complicated by small subsidiary terraces along its sides. The general structure as shown

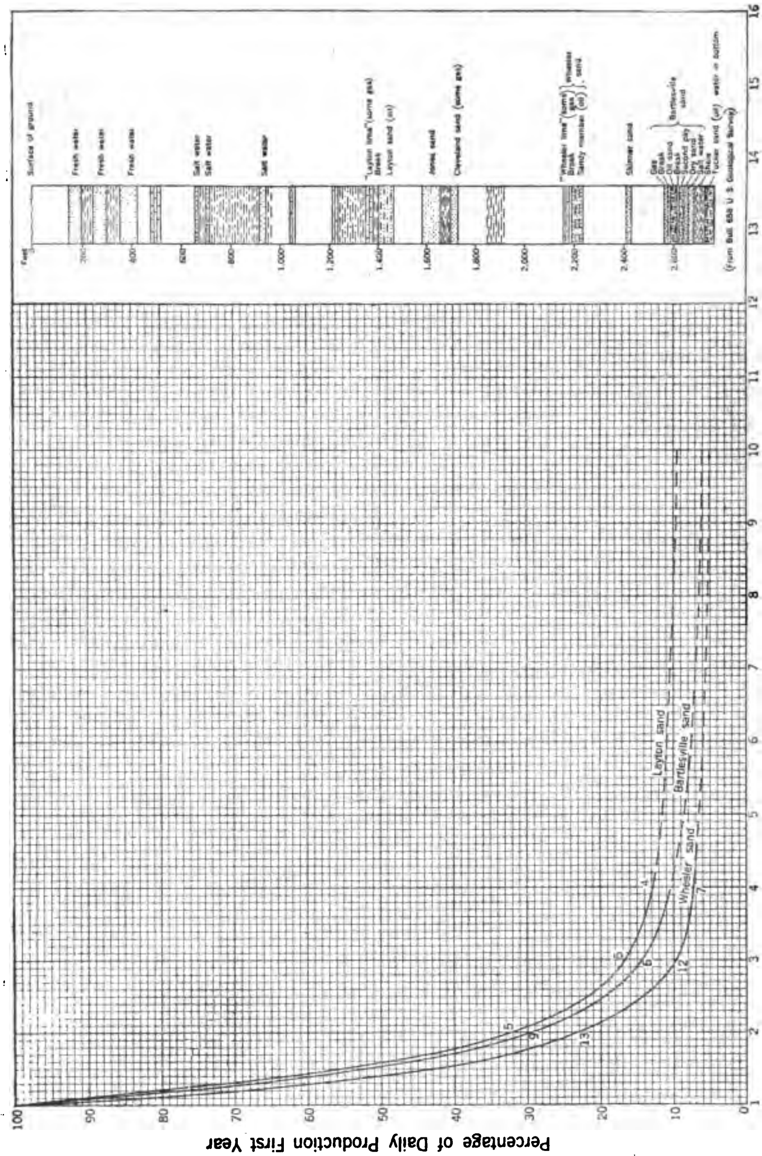


FIGURE 48.—Composite decline curves of the Layton, Wheeler, and Bartlesville sands in the Cushing field, Okla. Inset shows the columnar section of the formations penetrated.

by contours may be seen by referring to Plate I (p. 106). These contours have been generalized from Plate VIII of a report prepared by the author.[a] The contours have been generalized from the Wheeler

[a] Beal, C. H., Geologic structure of the Cushing oil and gas field, Okla., and its relations to oil, gas, and water: U. S. Geol. Survey Bull. 658, 1917, pp. 34–35.

sand because of its supposed equivalence to the Fort Scott limestone ("Oswego lime") upon which have been drawn the contours in the other parts of Oklahoma (Pl. I, p. 106).

COMPOSITE DECLINE CURVE.

Oil was discovered in the Cushing field near its center in March, 1912, in a well drilled to the Wheeler sand. For nearly two years the total output of the Cushing field came from the Wheeler and the Layton sands. The Bartlesville sand was discovered in December, 1913, and after that date drilling progressed rapidly. On many leases the wells produced from two or three sands, so that it has been difficult to obtain many records of production that give the actual output of wells producing oil from only one sand. A few such records have been collected, however, and composite decline curves constructed to show the average rate of decline of these wells. Figure 48 shows such decline curves for the Layton, Wheeler, and Bartlesville sands.

RATE OF DECLINE.

A word should be said as to the conditions influencing the rate of decline in production from these different sands. The Wheeler was principally a gas sand; as the gas usually overlies the oil it was difficult to drill into the oil sand until the pressure had fallen. The gas accordingly was allowed to waste in tremendous volumes for weeks at a time for the purpose of reducing the pressure, so that drilling could be resumed to the oil sand. As a result the wells of the Wheeler sand declined in output very rapidly, as shown in figure 48. Much the same condition was encountered in drilling wells to the Bartlesville sand, although this sand is much thicker and conditions were more complicated. The thickness of the sand, however, and the enormous gas pressure associated with the oil prevented such a rapid decline of oil production.

DATA ON TOTAL AND ULTIMATE PRODUCTION.

Table 3 (p. 118) shows the average production per acre of several different sections in the Cushing field. The following table gives the total production per acre of different sands on a few leases in the Cushing field. None of the tracts for which statistics are given supported wells more than three or four years old.

TABLE 5.—*Total production per acre of different sands to Jan. 1, 1916, on several leases in the Cushing field (Okla.).*

Lessor.	Section.	Township.	Range.	Approximate average total output per acre.
Layton sand.				*Barrels.*
Lussie Heneha [a]	9	16	7	300
Johnny Jacobs	15	18	7	2,600
Emma Derrisaw	32	18	7	3,100
Wheeler sand.				
Bettie Cain	18	17	7	1,400
Chas. Kernal	30	18	7	900
Aggie Wacoche	29	18	7	500
Beeley Derrisaw (80 acres)	6	17	7	1,100
Dewey Bruner	18	17	7	1,000
Beeley Derrisaw (40 acres)	6	17	7	1,200
Newman Deere	7	17	7	1,100
David Barnett	19-20	17	7	1,100
Minnie Bearhead (80 acres)	7	17	7	1,600
Beeley Derrisaw (40 acres)	6	17	7	900
Mattie Coachman	20	17	7	1,000
Polly Derrisaw	29	18	7	3,500
Minnie Bearhead (80 acres)	7	17	7	1,800
Johnson Wacoche	20	18	7	2,600
Salo Fulsom	6	17	7	1,300
Miller Tiger [b]	17	17	7	1,900
William Jones	31	18	7	300
Bartlesville sand.				
Lessey Yarhala [c]	8	17	7	9,800
Emma Coker	16	18	7	5,500
S. Long	9	18	7	13,100
Mattie Jones	5	18	7	4,300
Lizzie Brown	9	17	7	22,100
Thos. Long	3	17	7	9,600
Moses Wiley	9	17	7	8,100
Jesse Tiger	17	17	7	2,700
Jenetta Tiger [c]	16	17	7	17,300
Jenetta Richards	4	17	7	9,000
Katie Brown	9	17	7	9,600
Walter Starr	8, 17	18	7	5,100
Amy Simpson	8	18	7	1,000

[a] Production about 1 year old.
[b] Includes oil from 1 Layton sand well.
[c] Includes oil from 1 Tucker sand well.

THE PONCA CITY FIELD.

The Ponca City field is in the north central part of Oklahoma, west of the Osage Indian Reservation, and chiefly in T. 25 N., R. 2 E. According to Ohern and Garrett,[a] the first well was drilled in this field in 1905. There are several productive sands that range in depth from about 500 feet to 2,000 feet. The first year's average daily production per well, as determined from the records of several wells selected at random, is 32 barrels. The general structure of the field is that of a well-defined anticline lying on the westward dipping monocline that constitutes the general structural feature of northeastern Oklahoma.

[a] Ohern, D. W., and Garrett, R. E., The Ponca City oil and gas field: Oklahoma Geol. Survey Bull. 16, 1912, 30 pp.

COMPOSITE DECLINE CURVE.

Not enough information was available for preparing appraisal curves or estimating charts for this field. From the few records

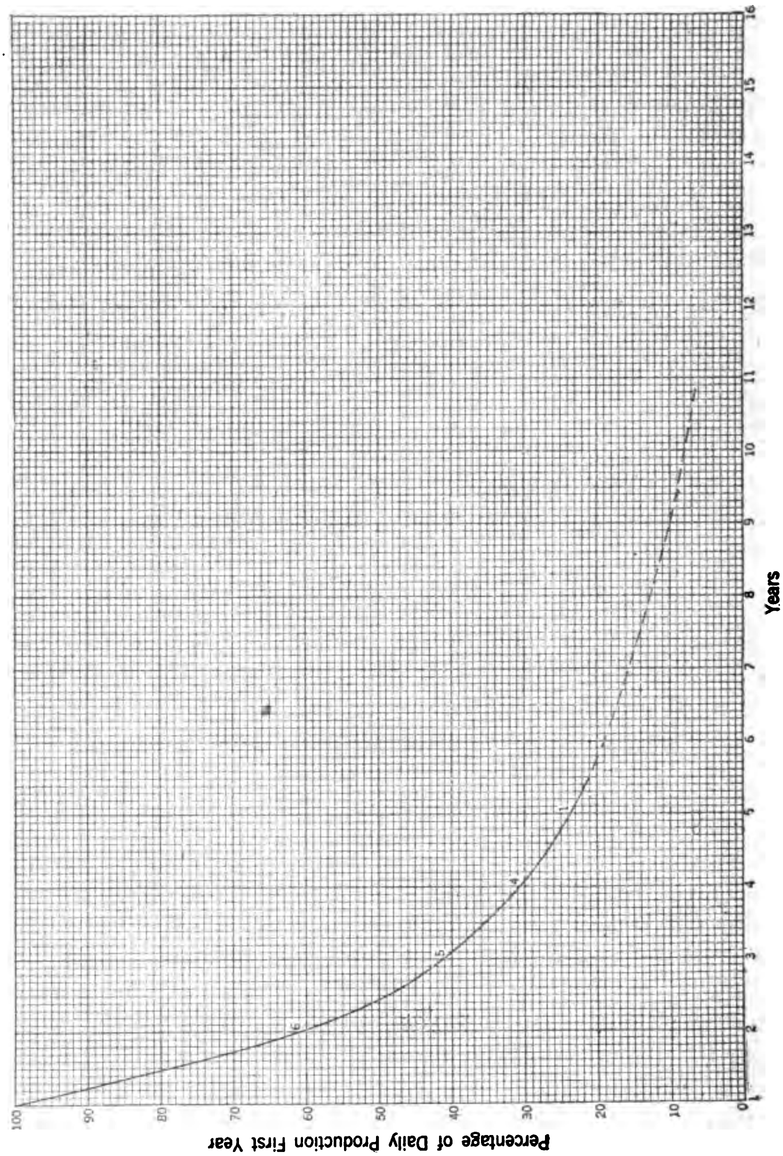


FIGURE 49.—Composite decline curve for the Ponca City field, Okla.

that could be obtained, however, the composite decline curve shown in figure 49 has been prepared.

FIELDS IN EAST CENTRAL OKLAHOMA.

Considerable information has been collected on the scattered fields in east central Oklahoma (fig. 50). These areas include what have

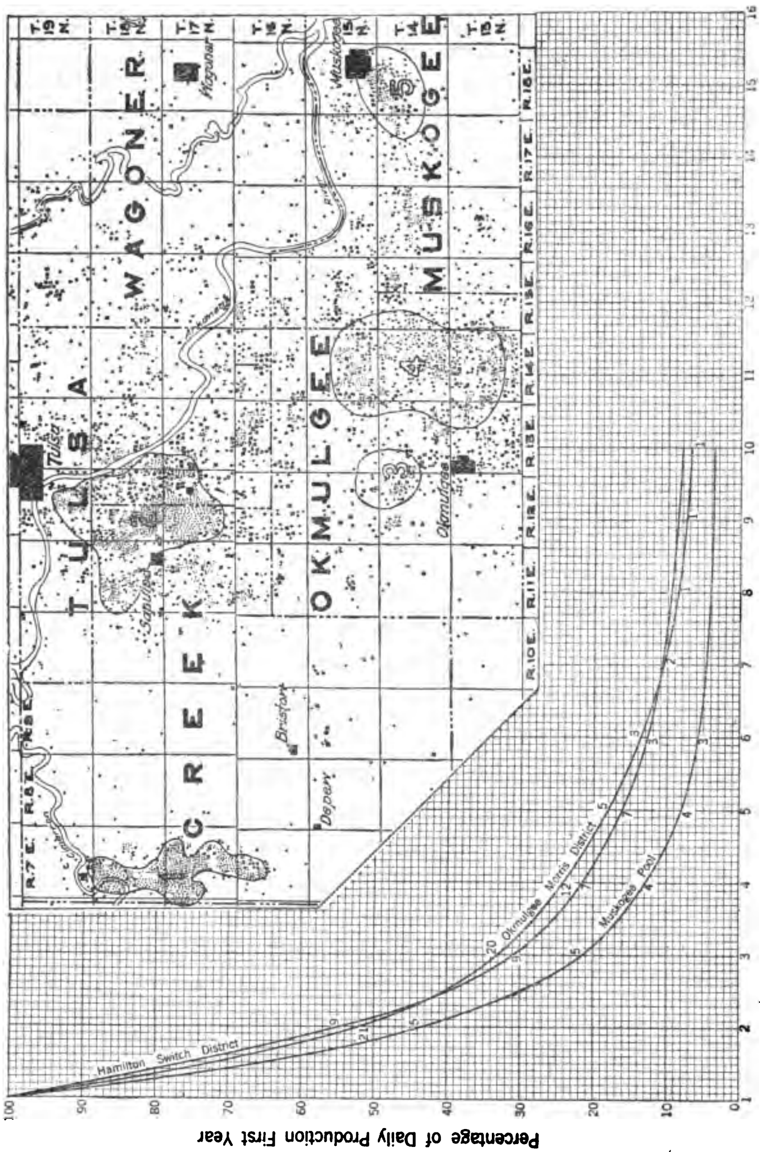


FIGURE 50.—Composite decline curves of the Okmulgee-Morris district, Hamilton Switch field, and Muskogee pool, Okla. Inset is map showing the location of (1) the Cushing field, (2) the Glenn pool, (3) the Hamilton Switch field, (4) the Okmulgee-Morris district, and (5) the Muskogee pool.

been called (1) the Okmulgee-Morris district, (2) the Hamilton Switch field, and (3) the Muskogee pool. All three are rather similar, except that the oil is not obtained wholly from the same sand.

Figure 50 shows the composite decline curves for the output of the three districts, as well as a small inset map giving the location of the fields in this part of Oklahoma.

OKMULGEE-MORRIS DISTRICT.

The Okmulgee-Morris district covers parts of what in other publications have been called the Bald Hill pool, the Morris pool, and the Booch sand area. Those properties for which production records were available are in T. 15 N., R. 14 E.; T. 15 N., R. 13 E.; T. 13 N., R. 14 E.; and T. 13 N., R. 13 E. The productive sands in the Bald Hill pool lie 1,300 to 1,700 feet deep, and that of the Morris pool is 1,500 to 2,000 feet deep. The Red Fork sand, which lies above the Glenn sand is 28 to 34 feet thick; the Glenn sand averages 16 feet, the Booch sand ranges from 28 to 34 feet; and the Morris sand from 12 to 34 feet. From 5 to 8 acres are allotted each well. The oil lies on terraces and noses on the westward dipping monocline that forms the chief structural feature of that part of Oklahoma. All the producing sands are in the Cherokee formation, the lower member of the Pennsylvanian series, of Carboniferous age, and vary in thickness and porosity. The daily production per well the first year of those wells for which the records were obtainable averaged 38 barrels.

HAMILTON SWITCH FIELD.

The Hamilton Switch field lies northwest of the Okmulgee-Morris district in T. 15 N., R. 12 E.; T. 14 N., R. 13 E.; and T. 14 N., R. 12 E. The producing sands lie 1,000 to 2,000 feet below the surface and are 19 to 50 feet thick. From 5 to 8 acres are allotted each well. Those wells for which records were obtainable averaged 56 barrels daily the first year.

MUSKOGEE POOL.

The Muskogee pool lies near the city of Muskogee. The composite decline curve shown on figure 50 was derived from the records of several properties and fairly represents the average rate at which the oil is obtained in that area.

THE HEALDTON FIELD.

The Healdton field, which lies in the southern part of Oklahoma, is on an anticlinal fold that strikes northwest, parallel to the trend of the Arbuckle Mountains. Wegemann and Heald[a] have

[a] Wegemann, C. H., and Heald, K. C., The Healdton oil field, Carter County, Okla.: U. S. Geol. Survey Bull. 621, 1915, pp. 13–30.

issued a preliminary report on this field, and Powers[a] has discussed in some detail the correlation of the sands and the structure of the field. The field was discovered in 1913 and at present comprises an area of approximately 7,000 acres. The sands range in depth from a few hundred feet to more than 2,000 feet, and some of the wells drilled have initial productions the first 24 hours of several thousand barrels. On account of the small size of some of the leases and the sands being in places shallow and in places unusually thick, the spacing of the wells is close, about 3 acres per well in many parts of the field. Had it not been for the thickness of the oil sand the decline of the wells in the field would have been much more rapid than it has been. On the few properties for which records were available the average daily production of the wells was 67 barrels during the first year. Figure 51 gives the composite decline curve for this field.

Several of the Healdton properties have remarkable records. A property in section 31, T. 3 S., R. 3 W., after producing only one year, made about 11,500 barrels per acre. Another property in section 4, T. 4 S., R. 3 W., at an average age of 1½ years made 5,300 barrels per acre. A third property first drilled in April, 1914, with 4 wells producing that year, 13 wells the next year, and 53 wells the next year, yielded 29,450 barrels per acre to the end of 1916. However, as has been stated, the spacing of the wells in the Healdton field is close, and although the depths are not great, the sands are so thick as to yield a large output in a short time. This does not mean, however, that the Healdton field will not continue producing for several years; the thickness of the sands guarantees this.

FIELDS IN SOUTHEASTERN KANSAS.

Several shallow and at present rather unimportant oil fields in southeastern Kansas were discovered several years before oil was found in Oklahoma. Oil is obtained from the Cherokee member of the Pennsylvanian series, and in structure and character the fields are like the Nowata and Bartlesville districts in northeastern Oklahoma. Figure 52 gives composite decline curves for wells of three different sizes in the Neodesha field, Wilson County, Kans. In this figure the upper curve shows the average decline of five properties with wells that averaged less than one barrel daily the first year; the lower curve represents the composite decline of the wells on three properties on which the wells during the first year produced 9 to 11 barrels daily; and the middle curve gives the average decline of the wells on all the properties for which production records were available.

[a] Powers, Sydney, Age of the oil in the southern Oklahoma fields: Am. Inst. Min. Eng. Bull. 131, November, 1917, pp. 1971–1982.

The first curve is of considerable interest, as it shows that during the second year a well of this output will make an average of about 86 per cent of its first year's production. For wells that during the

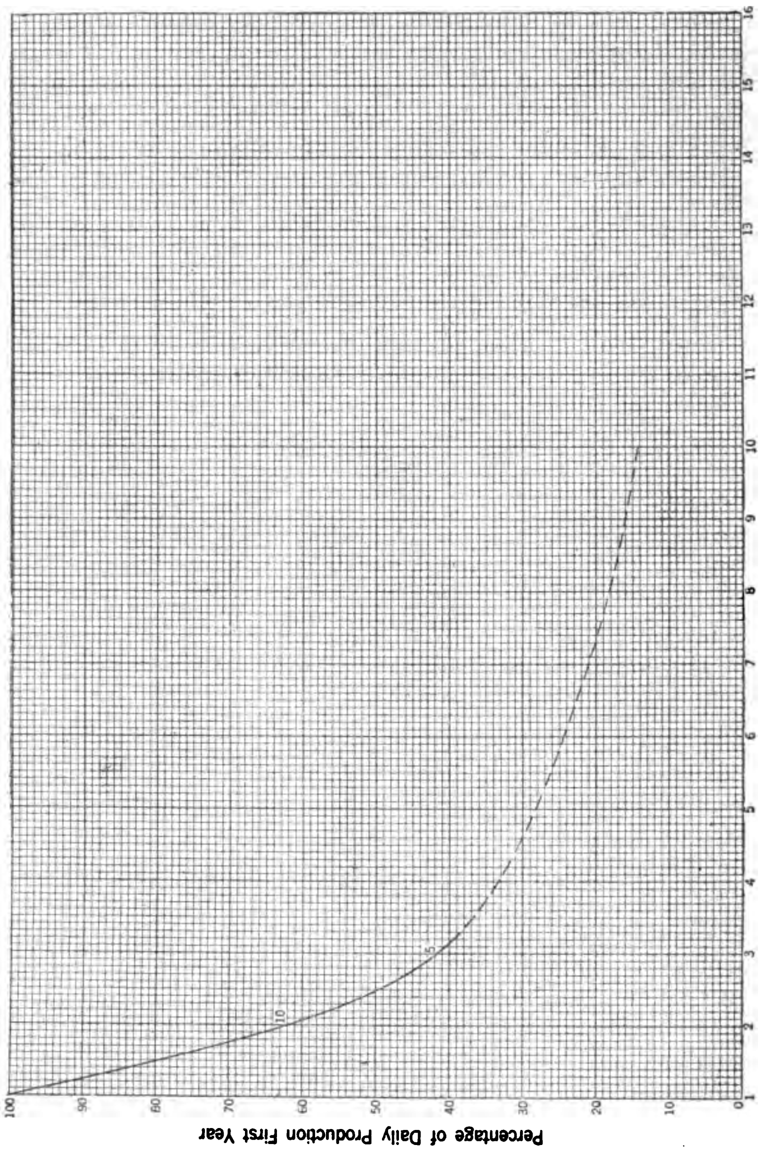


FIGURE 51.—Composite decline curve for the Healdton field, Okla.

present year produced 9 to 11 barrels daily, the second year's production is about 57 per cent as much. The average initial production of the wells on 14 properties from which the average curve was compiled amounted to only 3.9 barrels a day during the first year.

At present the most important fields in Kansas are the Augusta and the El Dorado, a few miles west of the shallow district. Several of the wells in these fields have been very productive. Table 6 gives

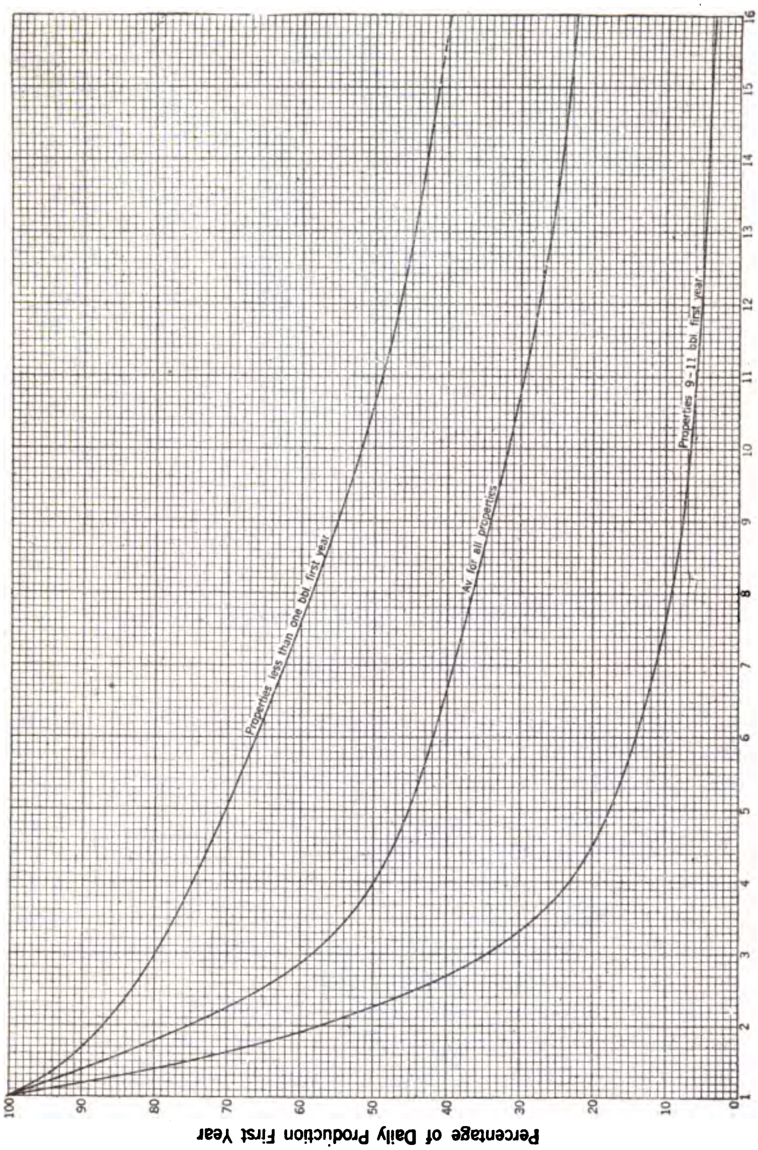


FIGURE 52.—Composite decline curves for wells of different output in the shallow Neodesha oil field of southeastern Kansas.

the oil per acre produced to March 31, 1917, by 27 properties in the Augusta field. The reader should note that some of these properties, in view of their age, have been very productive.

TABLE 6.—*Productivity and age of a few properties in the Augusta field, Kans.*

Property.	Average age.	Wells producing March, 1917.	Production to Mar. 31, 1917.	Total production per acre.
	Months.		*Barrels.*	*Barrels.*
1	3	2	13,200	825
2	16	7	96,500	1,720
3	12	2	3,160	197
4	2	1	15,700	1,970
5	18	7	126,000	2,250
6	16	3	26,500	1,100
7	11	8	172,000	2,700
8	12	3	116,000	4,840
9	8	4	36,700	1,150
10	12	6	348,000	7,250
11	8	2	95,300	6,000
12	7	2	16,100	1,000
13	5	1	9,000	1,200
14	9	1	80,000	10,000
15	10	7	72,800	1,300
16	9	12	1,333,000	13,900
17	14	8	83,600	1,300
18	17	18	333,000	2,300
19	7	1	26,500	3,300
20	21	8	118,500	1,850
21	16	13	2,075,000	20,000
22	21	13	164,500	1,580
23	6	2	39,700	2,500
24	7	15	444,000	3,700
25	16	13	421,000	4,000
26	11	2	12,360	770
27	10	2	31,400	2,960
Total		163	6,309,520	
Average	11			4,800

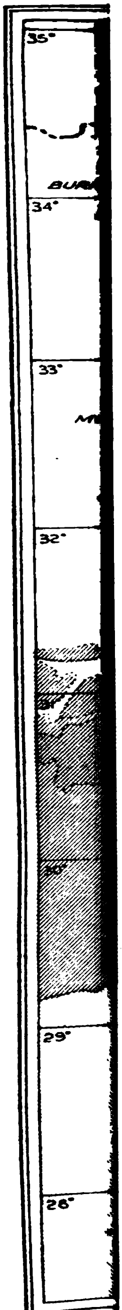
FIELDS IN NORTHERN TEXAS AND LOUISIANA.

GENERAL STATEMENT.

Plate II shows the general geology of eastern Texas, Louisiana, and southern Oklahoma, and the situation of the oil and gas fields. The fields of northern Texas, at the time of the compilation of data for this report, were not so important as they have since become and only a little information was obtained for the Electra, Burkburnett, and the Petrolia fields. The rocks near the surface in these fields are part of the Permian "Red Beds" (shown as Carboniferous on Pl. II), but the oil sands in some of these fields are probably within the underlying Pennsylvanian formations.

In northern Louisiana, considerable information was gathered from the Caddo field and the records of a few properties were collected from the Red River, Crichton, and De Soto fields. The surface formations of the Caddo, De Soto, and Red River fields in northern Louisiana are of Tertiary age, but the oil is obtained from the underlying Cretaceous formations. These fields are located on the Sabine uplift, a great anticline that extends across northern Louisiana.

BUREA



General

FIELDS OF NORTHERN TEXAS.

ELECTRA FIELD.

Lack of information on the fields in northern Texas made impossible the construction of curves other than the composite decline

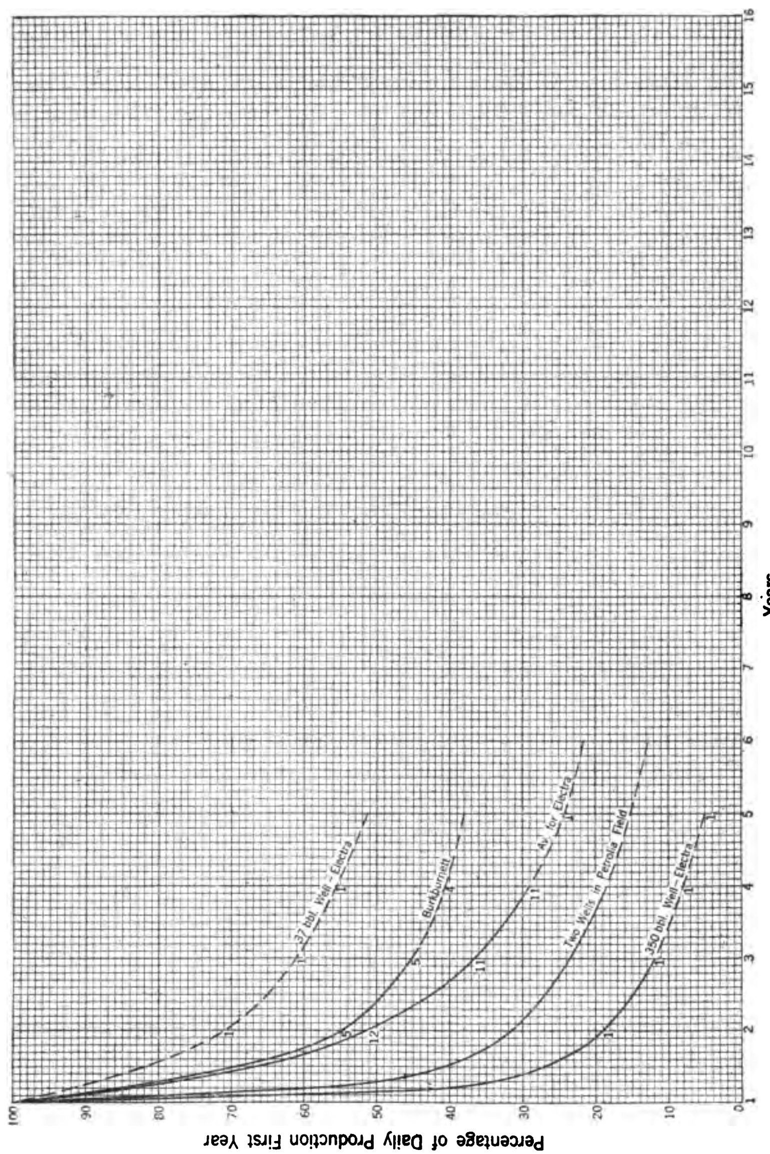


FIGURE 53.—Composite decline curves of a few wells in the Electra, Petrolia, and Burkburnett fields, Tex.

curves shown in figure 53. The average daily production per well on those properties in the Electra field for which information is available is about 75 barrels. During the first 24 hours, the ordi-

nary well, when the field was in its prime, made 50 to 250 barrels. The geologic structure is that of a monocline. Figure 53 shows the decline of a well that made 37 barrels daily the first year, as contrasted with the decline of a well that made 350 barrels daily the first year. The average decline curve of the Electra field is also shown.

BURKBURNETT FIELD.

In the Burkburnett field the average daily production the first year of the wells for which records are available was 36 barrels. During the first 24 hours most of the wells, when the field was in its prime, made 25 to 250 barrels. The productive sand is 1,700 to 1,800 feet deep. Figure 53 shows the average decline of the wells on five properties in this field. The data were collected before the recent new drilling was done.

PETROLIA FIELD.

In the Petrolia field, the individual records of only two wells on one property were available. These wells the first year averaged 60 barrels daily per well. The curve showing the decline of these two wells is given for what it may be worth.

FIELDS OF LOUISIANA.

THE CADDO FIELD.

The Caddo field (Pl. II), one of the most productive in that part of the United States, is near Shreveport, in northern Louisiana. Most of the oil comes from the Woodbine sand of Upper Cretaceous age, which lies at a depth of 2,000 to 3,000 feet. The structure of the field is anticlinal, the oil being found usually on the crest or sides of the arch. Production records were available from about 34 properties in three different districts—the Mooringsport, Jeemes Bayou, and Monterey. During the first year the average daily production per well for the wells on all the properties was 66 barrels, with a range of 7 to 385 barrels daily. The spacing of the wells ranges from 5 to 10 acres per well.

APPRAISAL CURVE.

Figure 54 shows the appraisal curve constructed from the records of the production of 34 properties. The curves are fairly trustworthy and estimates of future and ultimate production may be made in this field with considerable assurance of reliability.

COMPOSITE DECLINE CURVE.

Figure 55 shows the composite decline curve for the Caddo field as a whole and also for two of the more important districts. As the

figure shows, from the third to the eighth year the average curve for the whole field is below that of the two districts. The cause of this variation is that records from other districts were used in the calculations for the average curve for the field. Figure 55 also shows, in the inset, the decline of the first year's daily production of the wells drilled during consecutive years (see p. 51).

ESTIMATING CHART.

Figure 56 shows the chart prepared for rapidly estimating future production in the Caddo field. Being based on the appraisal curve of the field, which is considered fairly accurate, it may be used within the limitations for the use of such charts, with reasonable certainty.

GENERALIZED DECLINE CURVE.

Figure 57 has already been mentioned, but the use of this curve in estimating future production may be mentioned again. On the curves the decline in production of various properties has been plotted by the use of different symbols representing the daily production per well for each year. It is noteworthy that practically none of the declines from individual properties fall outside the limits established by these generalized curves.

DATA ON ULTIMATE PRODUCTION.

Some of the leases in the Caddo field have been very productive. The following table gives the production per acre and age of three of the more productive leases in this field:

Production and age of three leases in the Caddo field.

Property.	First produced.	Number of wells.	Total produced to 1916.	Production per acre.	Approximate depth of sand.
	Year.		*Barrels.*	*Barrels.*	*Feet.*
A	1911	8	1,407,240	22,000	2,350
B	1911	4	390,381	12,200	2,300
C	1913	11	494,820	44,800	2,250

RED RIVER, CRICHTON, AND DE SOTO FIELDS.

The Red River, Crichton, and De Soto fields lie southeast of the Caddo field on the Red River (Pl. II), and are not of great importance because of their small output. Most of the oil comes from the Woodbine sand, of Cretaceous age, which lies 2,450 to 2,550 feet deep. Between five and eight acres are allotted to each well. The average daily production per well during the first year of five proper-

wells. Figure 58 shows also the average decline curve for all three fields.

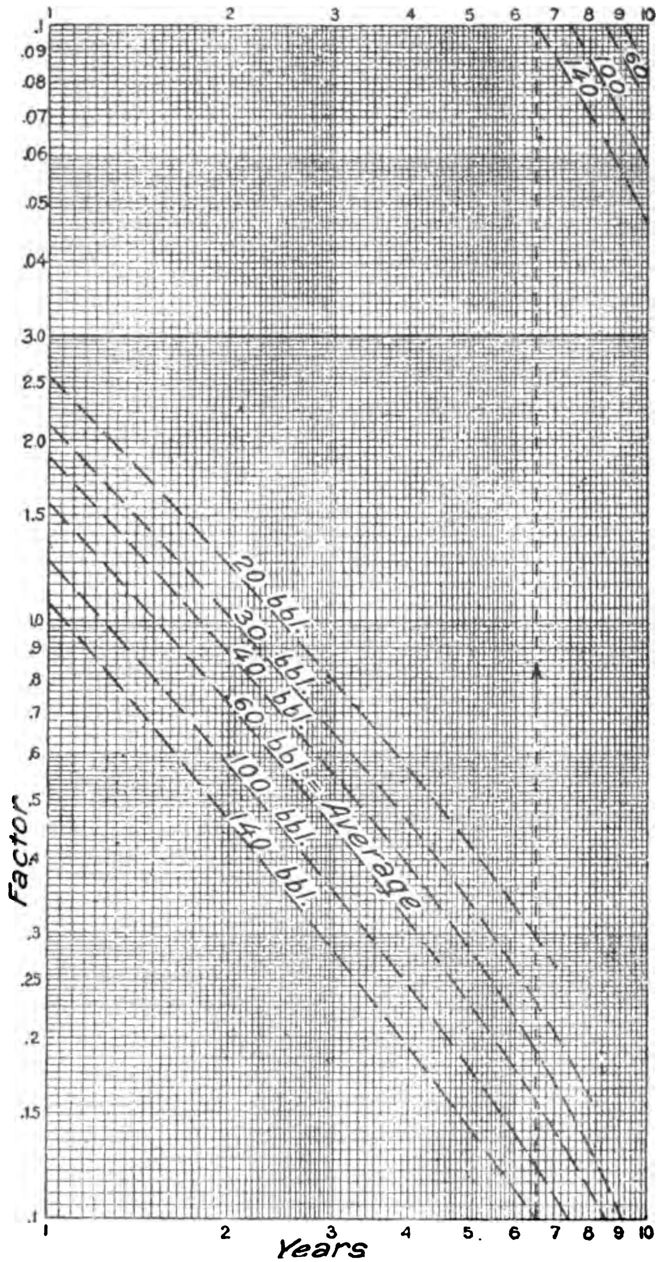
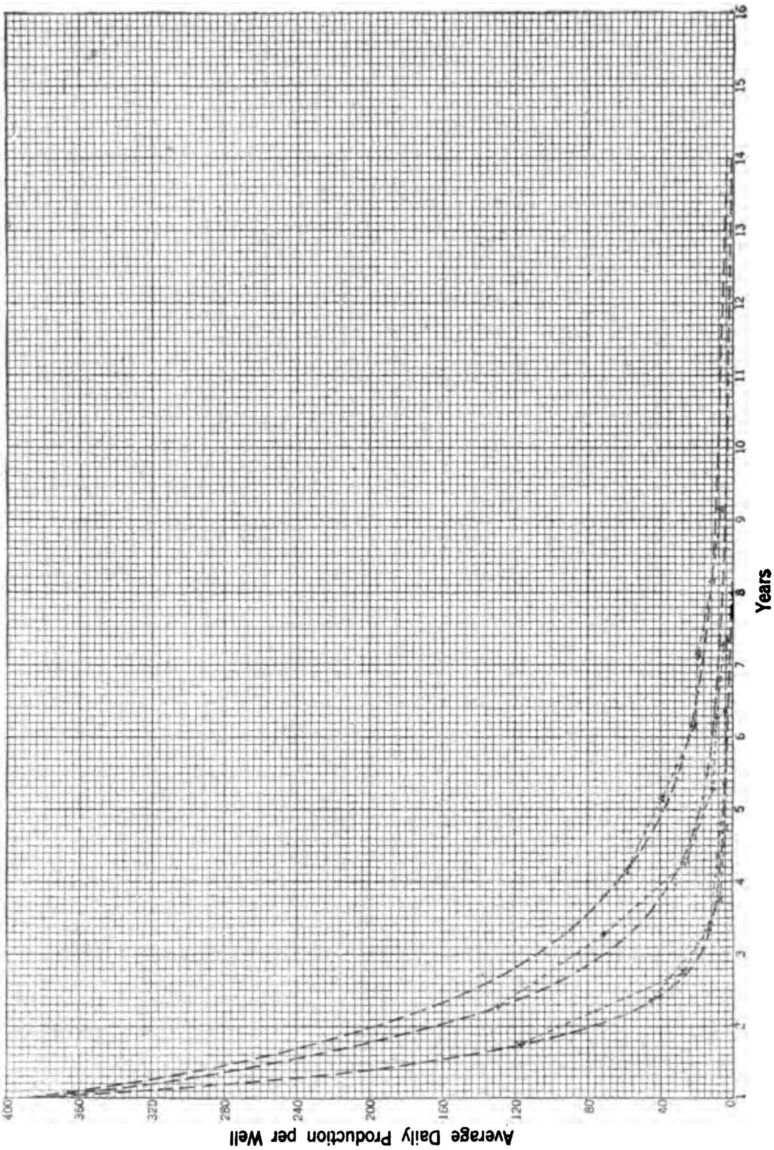


FIGURE 56.—Estimating chart for the Caddo field, La.

In all these fields the maintenance of a set production seems practically impossible on account of the extremely rapid decline in the

output of old wells and in the initial output of new wells. For instance, from one lease during the second year, although seven new wells were brought in, the production per well was 18 per cent of



FIGURES 57.—Generalized decline curves for the Caddo field, La. Production is in barrels.

that during the first year. On another lease the average daily production per well for the second year was 32 per cent of that for the first year. During the first year there were six wells and during

the second year nine wells producing. As a third example, the composite decline of the production of 12 leases in the Crichton pool,

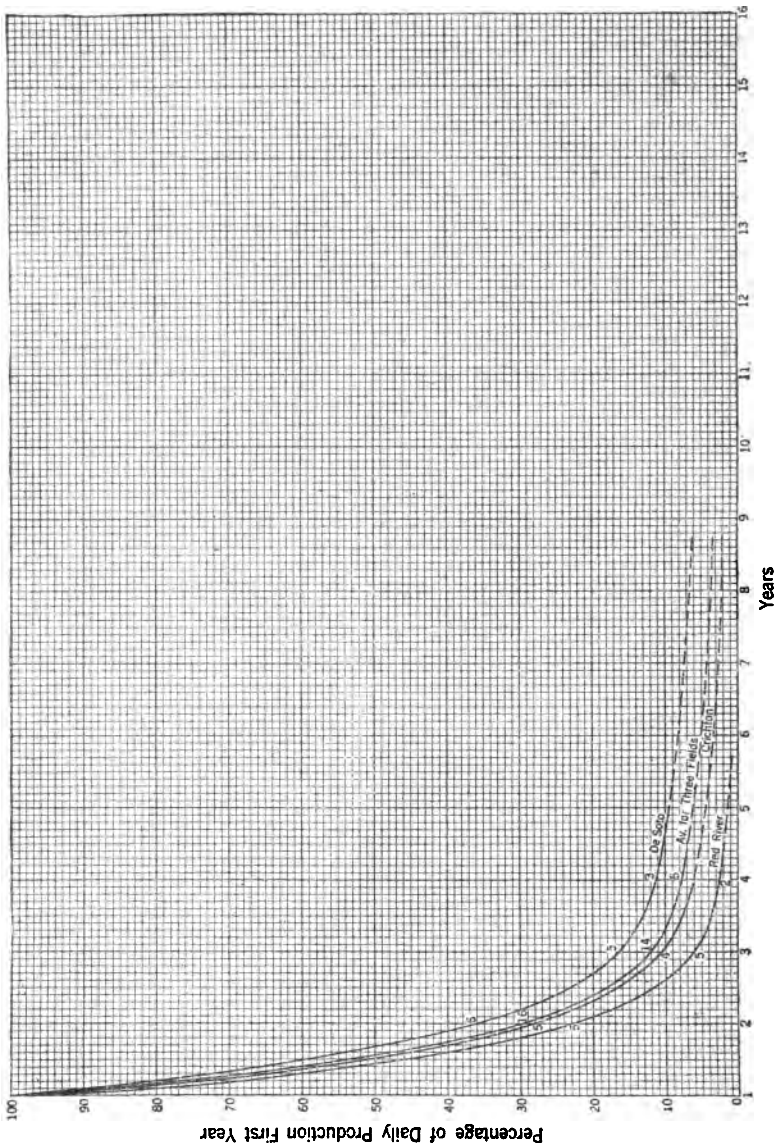


FIGURE 58.—Composite decline curves for the De Soto, Crichton, and Red River fields, La.

with many new wells producing each year, gave the figures shown in the table following:

Decline in production of 12 leases in the Crichton pool.

Year.	Wells producing.	Percentage of first year's daily production per well.
		Barrels.
1914	22	100
1915	70	50
1916	118	27
1917	130	18

Evidently, although the number of wells producing increased rapidly, the average daily output for each well fell off decidedly. In fact, the cause for the decrease in the actual production per well was the rapid decrease in initial production.

On one property in the Red River field, six wells the first year had an average daily production of 260 barrels. The next year 11 wells made an average daily output of 61 barrels, or 23.5 per cent of the average daily production for the first year. There were seven new wells drilled the third year, but their "flush" production failed to maintain the average daily production per well, which dropped to 20 barrels, or 7.9 per cent of the first year's production. The table following gives the average daily production from several properties in this field, and shows that the initial production must decline rapidly.

Decline of wells on several properties in the Red River field.

Year.	Wells producing.	Per cent of the first year's daily production per well.
1915	7	100
1916	29	22
1917	31	4

THE GULF COAST FIELD.

Plate II shows several oil fields in the area of the Quaternary formations of the Gulf coastal plain. All these fields are associated with salt domes.

CLOSE SPACING OF WELLS.

Plates III and IV show the usual practice in spacing wells in the salt-dome fields, a practice that is largely the result of subdividing the productive area into extremely small tracts. Such close spacing, however, has surprisingly little effect on the rate at which the oil is produced, although it may materially shorten the life of the wells,

which often "go to water" very suddenly. From one-half acre to three or four acres is the area allotted each well in these fields.[a] There has been considerable discussion as to the necessity of such close drilling in salt-dome pools, but the writer believes that the practice is often justifiable because of the probable lack of communication between adjacent wells.

PRODUCTIVENESS OF FIELDS.

Some of the salt-dome fields have been extremely productive, and the figures for total oil produced per acre of drilled land show very high recoveries. For instance, Spindletop, according to Matteson,[b] has produced 45,000,000 barrels from 250 acres, or 180,000 barrels per acre, and other salt domes made the following outputs to January 1, 1917:

Total production to January 1, 1917, of various Gulf Coast pools.

Pool.	Barrels.
Sour Lake, Tex	45,000,000
Jennings, La	40,000,000
Saratoga, Tex	18,000,000
Batson, Tex	28,000,000
Humble, Tex	62,000,000

The average daily output per well the first year on several of these domes is as follows:

Average daily production per well the first year in various Gulf Coast pools.

Pool.	Average daily production per well, first year.	Number of properties.
	Barrels.	
Sour Lake	84	6
Spindletop	92	5
Saratoga	23	3
Humble Deep Sand [a]	289	5
Humble Cap Rock [b]	47	3

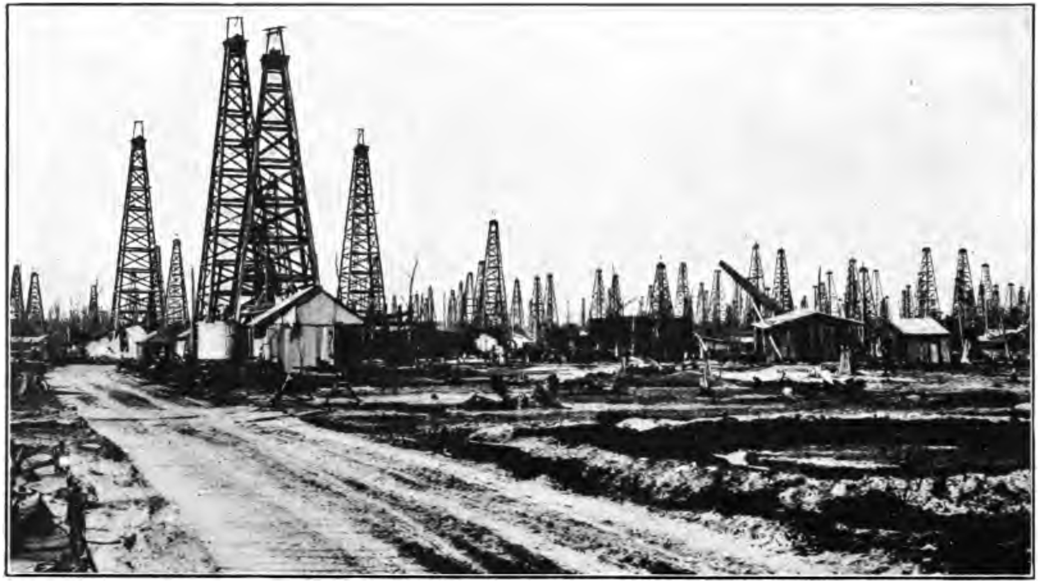
[a] Wells drilled to the sands that flank the Humble salt dome.
[b] Wells in the crest of the salt dome as distinguished from "deep-sand" wells in the flanks of the dome.

DECLINE OF FIELDS.

It is realized that a study of the decline of output in pools of this kind and under these conditions has small value, but enough information has been collected from the field, some of it on individual wells,

[a] From report of J. F. Seeman. Hearings before the Committee on Public Lands, House of Representatives, 65th Cong., 2d sess., p. 223.

[b] Matteson, W. G., Principles and problems of oil prospecting in the Gulf coast country: Am. Inst. Min. Eng. Bull. 134, February, 1918, pp. 430–431.



EXAMPLE OF CLOSE SPACING OF WELLS IN THE SALT-DOME POOLS OF THE GULF COAST. SHOWS A VIEW IN THE SOUR LAKE POOL (TEXAS).

to permit the construction of the composite decline curves shown in figure 59.

Much to the author's surprise the average decline of some of these pools was by no means as rapid as anticipated, in view of the close

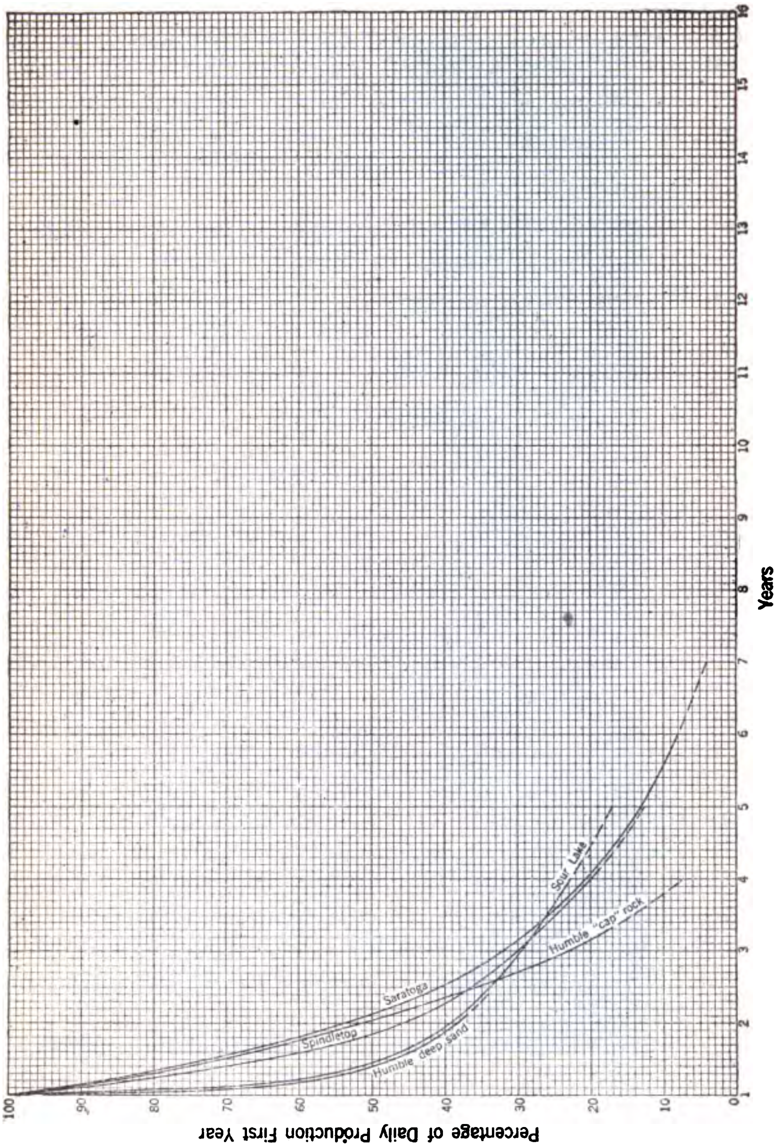


FIGURE 59.—Composite decline curves for several salt-dome oil pools, Texas.

spacing of the wells and the uncertainty as to conditions in the reservoir from which the oil comes. The lowest decline of any pool shown in figure 59 is that of the Humble Deep Sand, where the wells tap a

sand similar to the ordinary oil sand of other fields. The records of "Cap Rock" properties—properties with wells drilled on the crest of the Humble dome—show that during the second year the output of the wells averages about 51 per cent of the first year's output, but during the third year drops to 23 per cent of that of the first year. These averages are given for what they are worth, as it is realized that other wells may be drilled that will show widely different curves; moreover, it is not certain that the curves shown represent averages, for the small number of properties included may cause the curves to differ much from what they would be if based on several hundred properties.

Two wells in the Sour Lake field illustrate how small wells "hold up" better than large wells. The largest well for which a record was obtained, during the first year made 196 barrels daily, the other made 30 barrels. The next year the first well made 7 per cent and the second well 61 per cent of the first year's production.

ILLINOIS FIELDS.

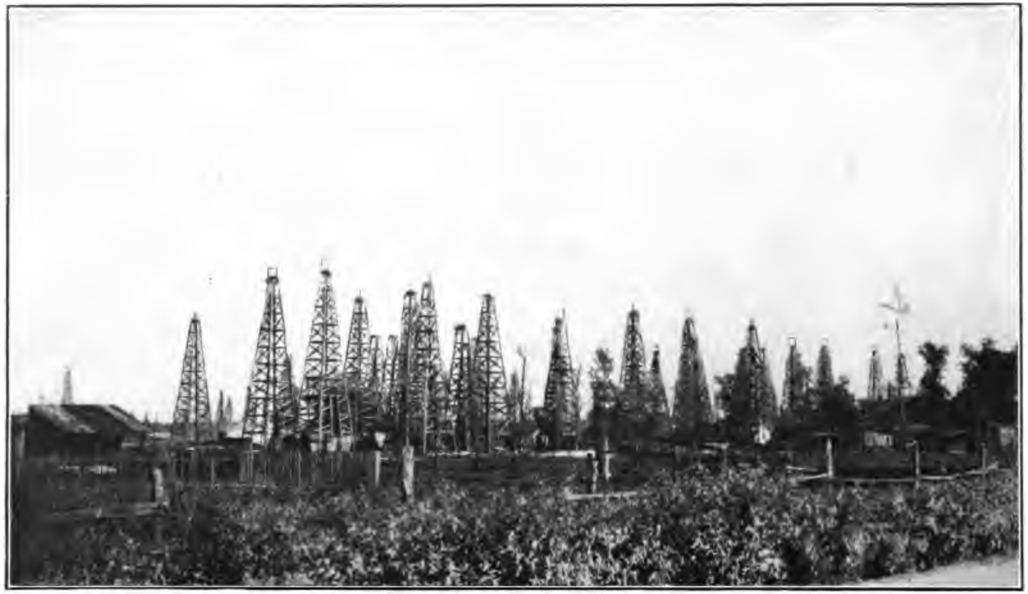
GENERAL STATEMENT.

Most of the oil produced in Illinois comes from three fields, the Clark County, the Crawford County, and the Lawrence County (fig. 60). These fields lie in the southeastern part of the State on the La Salle anticline, which plunges southeast. Smaller pools lie farther west in the Carlyle and Sandoval fields, and several less important pools occur in Montgomery, Macoupin, and Morgan Counties. The producing territory in the State covers about 230 square miles, and it had yielded more than 300,000,000 barrels of oil to the end of 1916, giving an average production per acre of about 2,000 barrels.

In the Clark County and Crawford County fields the productive sands lie from about 300 feet to more than 1,000 feet deep; in the Lawrence County pool the depth ranges from about 800 to 2,000 feet. In the three main fields the oil lies in sandstones in formations of Lower Pennsylvanian and Mississippian age. According to Kay [a], the Robinson sand in Crawford County averages about 25 feet thick, and the "pay" about 7 feet.

The area usually allotted each well in the Clark County and Crawford County fields is four to eight acres, and in the Lawrence County field about seven to 10 acres. In the Crawford County field the daily production per well the first year of the wells for which records were available was 11 barrels, whereas the similar average for both the Clark County and the Crawford County fields was about 10

[a] Kay, F. H., The oil fields of Illinois: Bull. Geol. Soc. Am., September, 1917, p. 666.



ANOTHER EXAMPLE OF CLOSELY SPACED WELLS IN THE SALT-DOME POOLS. SHOWS A GROUP OF WELLS IN THE HUMBLE POOL (TEXAS).

barrels. In the Lawrence County field the average daily production the first year of wells on properties from which records were available

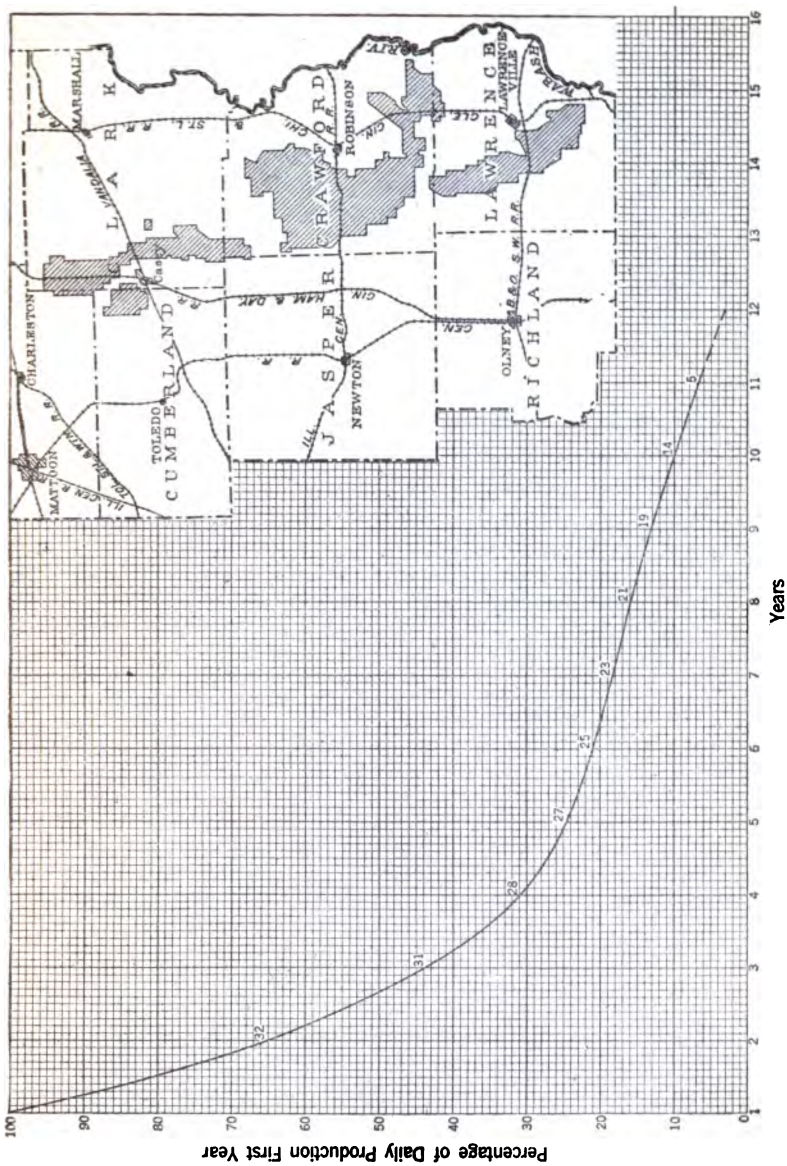


FIGURE 60.—Composite decline curve for the Clark County field, Ill. Inset, sketch map of southeastern Illinois, showing the principal Illinois oil fields.

varied from two to three barrels to about 100 barrels. The relation of initial production the first 24 hours to the average daily production the first year in the Lawrence County field is shown in figure 15, page 61.

CLARK COUNTY AND CRAWFORD COUNTY FIELDS.

On account of the similarity of geologic conditions and drilling practice in the Clark County and Crawford County fields, these fields are discussed together. The sands from which the wells produce are the same, although they come nearer the surface in Clark County. The production records of 60 properties in the Crawford County field and of 32 properties in the Clark County field were available for study. In the excellent reports of the Geological Survey of Illinois much information is presented regarding the underground conditions in the oil fields of the State. The data on the thickness of the sands in different fields, the depth of wells, and the detailed information on underground structure given in those reports have been of material aid in the preparation of the present bulletin.

APPRAISAL CURVE.

The appraisal curve shown in figure 5, page 33, is based on the records of properties in both the Crawford County and Clark County fields, and includes a few records from the Flat Rock pool, which lies in the southeastern part of the Crawford County field. In figure 5 the crosses represent the ultimate cumulative percentages of properties in the Clark County field and the dots those of properties in the Crawford County field. In general, the ultimate cumulative percentages of wells in the Clark County field having a given initial yearly output are a trifle higher than those of wells of the same initial yearly output in the Crawford County field. Persons who desire to make estimates of future and ultimate production of properties in the Clark County field should raise the maximum ultimate production line slightly, although the average and minimum curves for such estimates are practically the same as those for properties in the Crawford County field. Records of 89 properties were used in preparing this chart, and it is believed the curves can be used with little fear of large error.

COMPOSITE DECLINE CURVES.

For preparing composite decline curves, the records of properties in the Clark County field were separated from those of properties in the Crawford County field. Figure 60 gives the average decline of 32 properties in the Clark County field, and figure 61 that of 60 properties in the Crawford County field. As the figures show, an average well in the former field yielded during its second year about 65 per cent of its first year's output, whereas in the latter field a well during its second year yielded about 52 per cent of its first year's output. In figure 60 the curve trends rather suddenly downward after the eighth year. This was because of the reduction in the

number of properties used in determining the average, and does not fairly represent the actual action of the average well in that field.

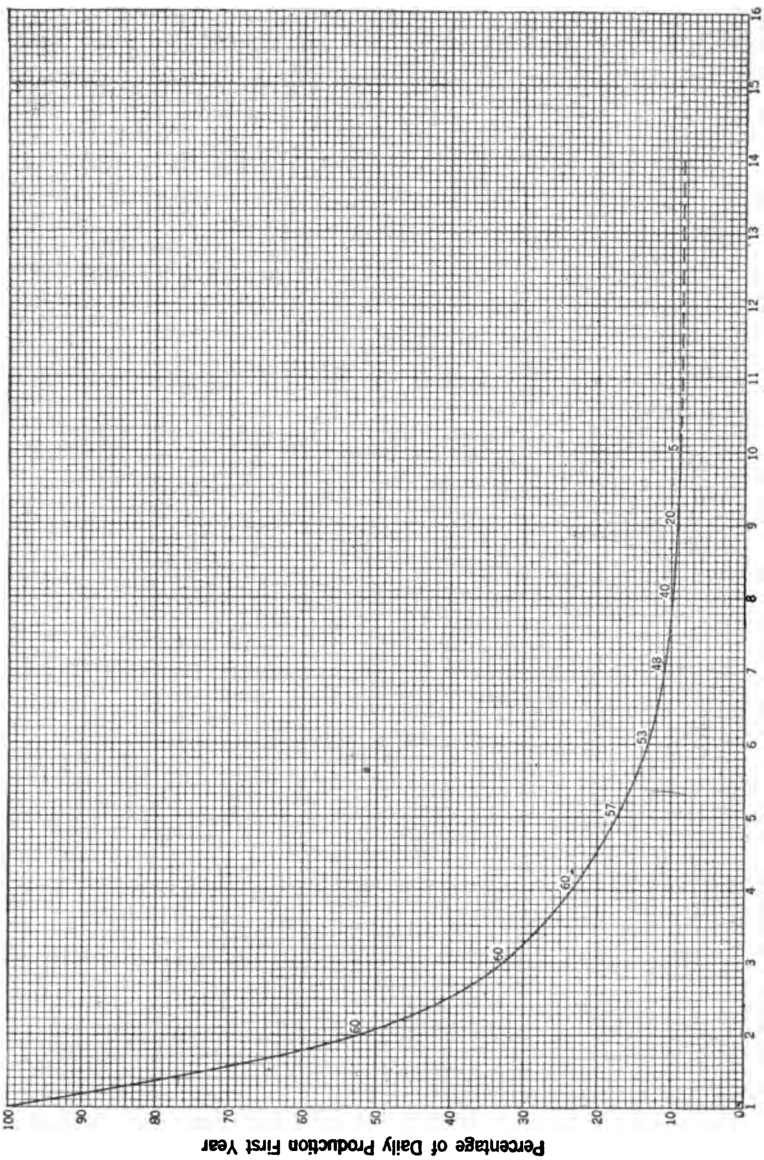


FIGURE 61.—Composite decline curve for the Crawford County field, Ill.

ESTIMATING CHART.

Figure 21, page 78, shows the chart prepared from the appraisal curve for making rapid estimates of future production of properties in the Clark County and Crawford County fields. As it is based on

the appraisal curve, which is assumed to be fairly accurate, it can be used without fear of any great error.

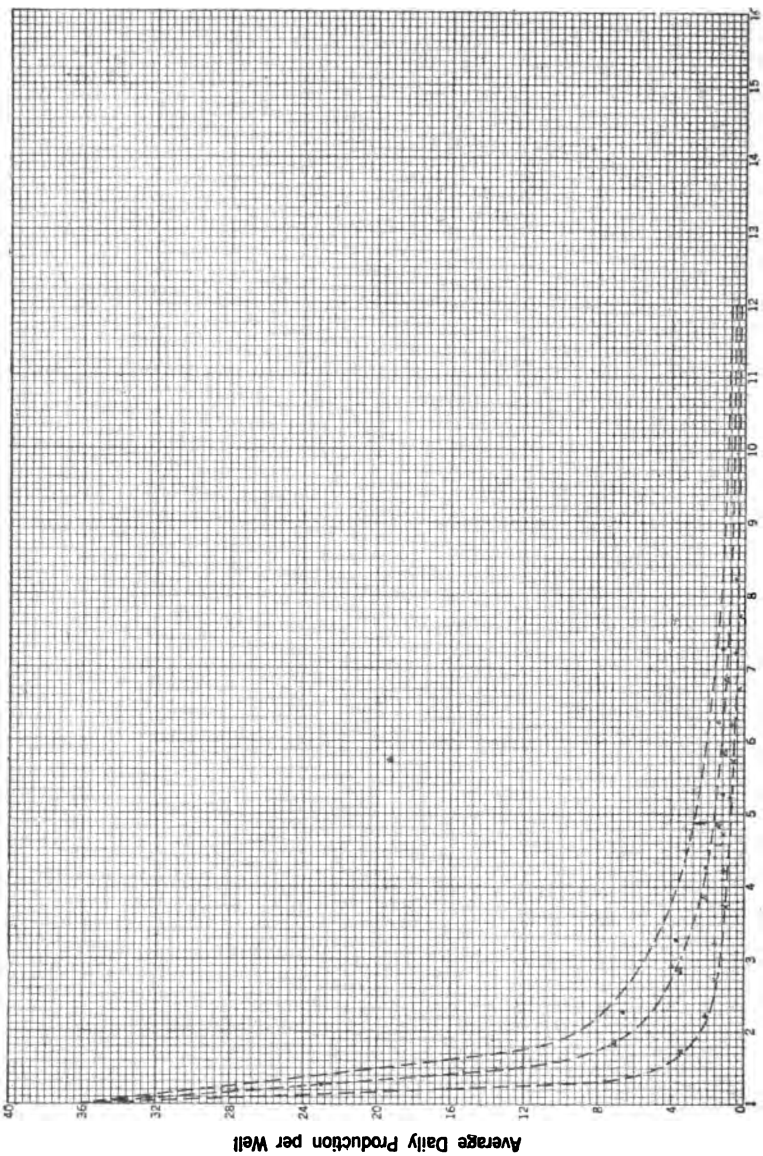


FIGURE 62.—Generalized decline curves for the Clark County and Crawford County fields, Ill.

GENERALIZED DECLINE CURVES.

Figure 62 shows the generalized decline curves prepared from the appraisal curve (fig. 5, p. 33) for this area. The actual declines of several different properties is indicated by different symbols.

CURVES SHOWING SAND THICKNESS, WELL DEPTHS, AND SPACING.

On account of the wealth of information available, the ultimate cumulative percentages of different properties in the Clark County and Crawford County fields have been plotted against (1) the approximate number of acres per well, (2) the average depths of the productive sand under each property, and (3) the average thickness of these sands. The charts thus prepared have been printed as figure 7 (p. 44), figure 9 (p. 46), and figure 8 (p. 45), respectively to show the manner in which the ultimate cumulative percentage varies with each of these three factors. In plotting figure 7 and figure 9, records of the Clark County properties were omitted because of the difference in acreage per well and average depth of sand. In figure 8, showing the relation of the ultimate cumulative percentage to the average thickness of sand, records of properties in the Clark County field were included.

DATA ON TOTAL PRODUCTION.

The following table gives statistics on the productiveness of 48 leases in the Clark County and Crawford County fields.

TABLE 7.—*Average total production per acre of 48 properties in Clark County and Crawford County, Ill.*

Property.	Location.		Number of years producing.	Average total production per acre.
	Section.	Township.		
Clark County.				*Barrels.*
1	14	Johnson	10	600
2		do	9	400
3	15	do	9	200
4	22	do	10	1,100
5	22,23	do	10	1,400
6	26	do	10	11,000
7	15	do	10	2,900
8	15	do	10	10,000
9	15	do	10	3,000
10	27	do	10	9,000
Crawford County.				
1	6	Oblong	10	3,100
2	34	Martin	10	1,700
3	3	do	10	400
4	16	5 N., 11 W	9	1,700
5	12,13	Oblong	9	1,130
6	30	do	9	4,200
7	50	do	9	700
8	30	do	9	1,300
9	25	Martin	9	2,300
10			9	1,500
11			9	1,500
12			9	1,500
13			9	1,300
14	16	Oblong	9	2,800
15			9	1,300
16	28	Martin	9	4,400
17	16	Oblong	9	2,000
18	15	Montgomery	8	1,000
19	14	do	8	800
20	15	do	8	750
21	14	7 N., 13 W	8	2,300

TABLE 7.—*Average total production per acre of 48 properties in Clark County and Crawford County, Ill.*—Continued.

Property.	Location.		Number of years producing.	Average total production per acre.
	Section.	Township.		
Crawford County—Continued.				*Barrels.*
22	21	.....do	8	3,200
23	5	.....do	8	5,000
24	13	.....do	8	1,000
25	15	5 N., 13 W	8	1,300
26	14,24	7 N., 13 W	8	3,000
27	13	.....do	8	2,200
28		Oblong	8	1,700
29	20	.....do	8	2,800
30			8	1,500
31			8	800
32	21	6 N., 12 W	8	2,900
33	20	.....do	7	2,000
34	6	5 N., 12 W	7	1,500
35	22	Honey Creek	8	1,400
36	3	7 N., 13 W	6	5,800
37	28	Martin	7	1,500
38	21,35	Petty	5	2,400

LAWRENCE COUNTY FIELD.

In general, the properties in this field are much more productive than those in Clark and Crawford Counties. There are more productive sands, they lie deeper, and some of the sands are much thicker than any in the other two fields.

APPRAISAL CURVE.

Figure 63 shows the appraisal curve constructed from the production records of properties in Lawrence County. Not as much information was available as for the properties in Clark and Crawford Counties, so the curve is less trustworthy.

COMPOSITE DECLINE CURVE.

Figure 64 shows the composite decline curve of the properties in Lawrence County. The reader should note that the average well in this field during its second year makes about 61 per cent of its first year's production, whereas the corresponding percentages for wells in the Clark County and Crawford County fields are 65 and 52 per cent, respectively.

ESTIMATING CHART.

Figure 65 shows the chart prepared from the appraisal curve for use in making rapid estimates of future production. If the average daily yield per well during the first year's production of a property is not known, it may be safely taken as 10 barrels.

THICKNESS AND DEPTH OF SAND.

Figure 66 shows that the average thickness of sand on properties for which the records were available ranged from about 14 to 40 feet.

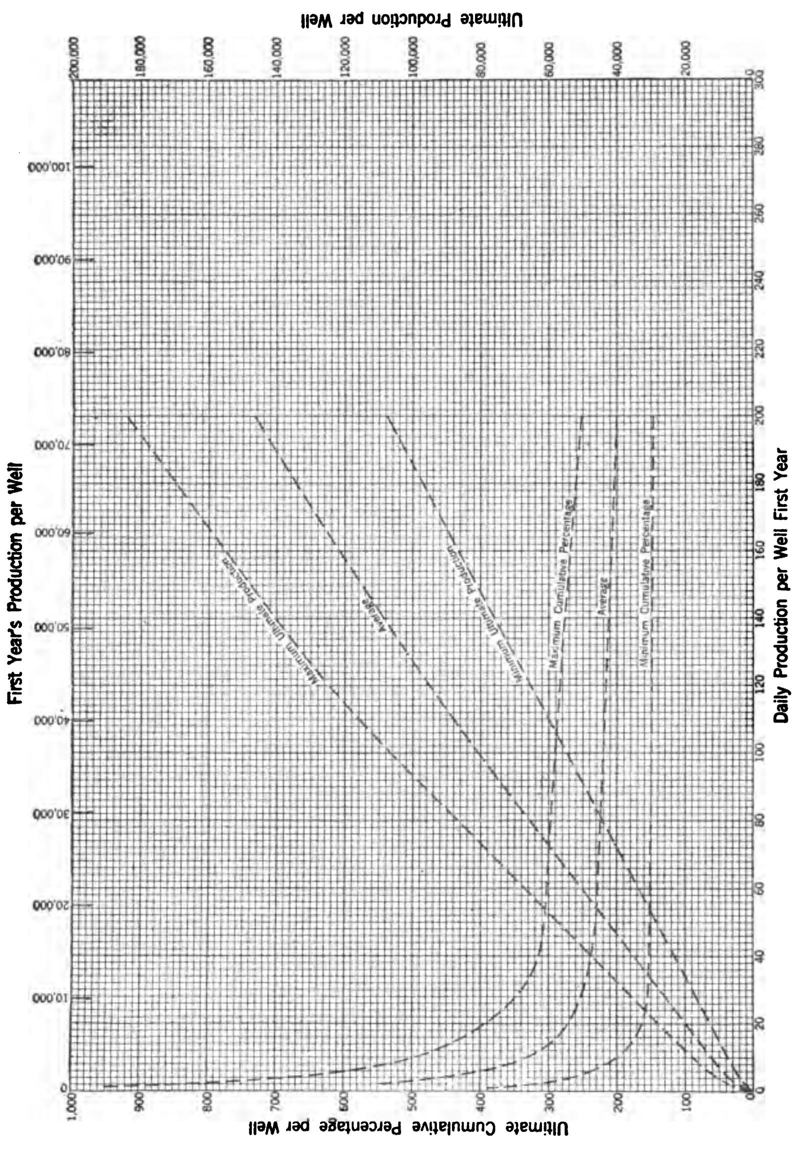


FIGURE 63.—Appraisal curve for the Lawrence County field, Ill. Production is in barrels.

The figure also shows the relation of well depths to the ultimate cumulative percentages.

DATA ON TOTAL AND ULTIMATE PRODUCTION.

Some of the properties in Lawrence County have been among the most productive in the United States. This is because of the num-

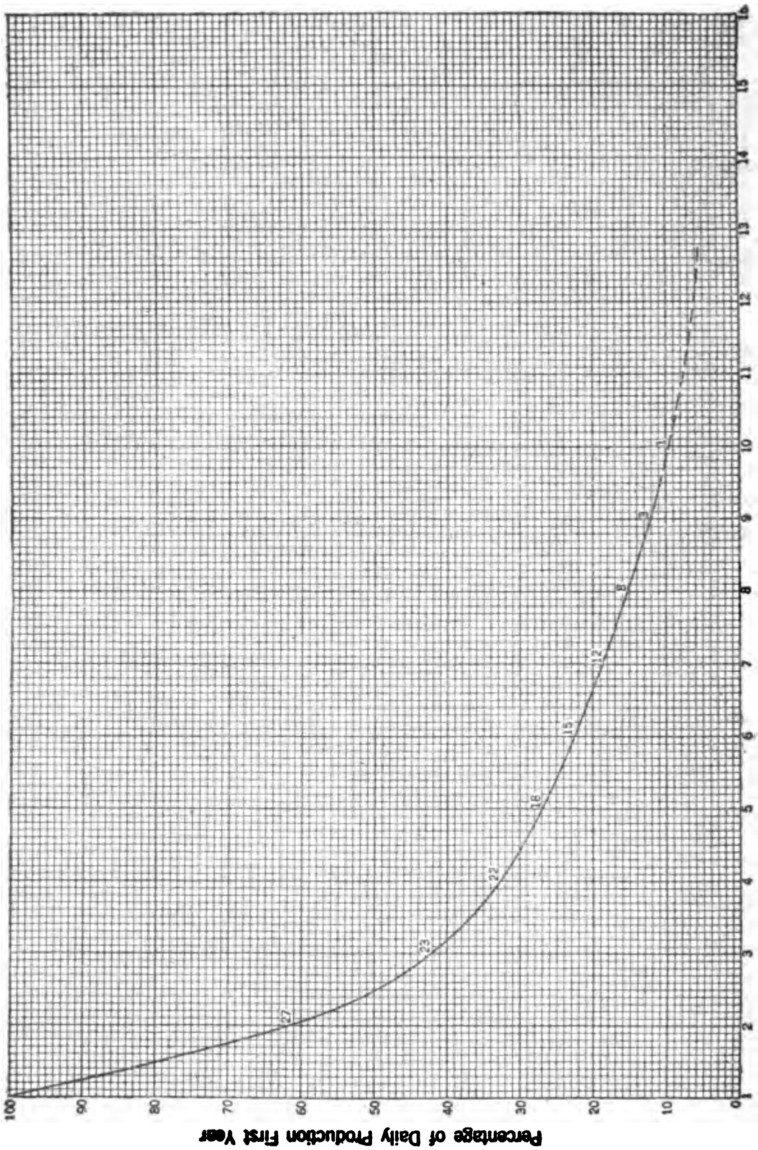


FIGURE 64.—Composite decline curve for the Lawrence County field, Ill.

ber of sands producing and the great thickness of some of them. On many properties the wells tap four sands; these range in depth from 800 to 2,000 feet. The table following has been taken directly

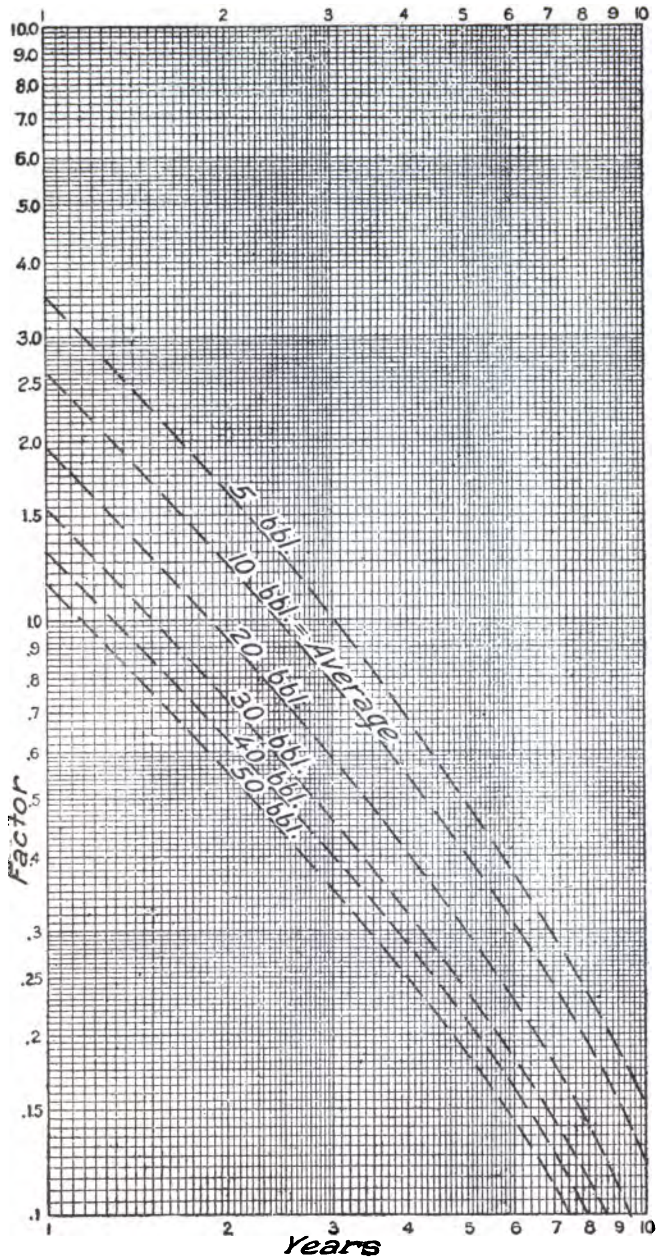


FIGURE 65.—Estimating chart for the Lawrence County field, Ill.

from an article by Kay.[a] It also includes information on the production from the Casey and Robinson sands in Clark and Crawford Counties.

[a] Kay, F. H., The oil fields of Illinois: Bull. Geol. Soc., America, September, 1917, p. 666.

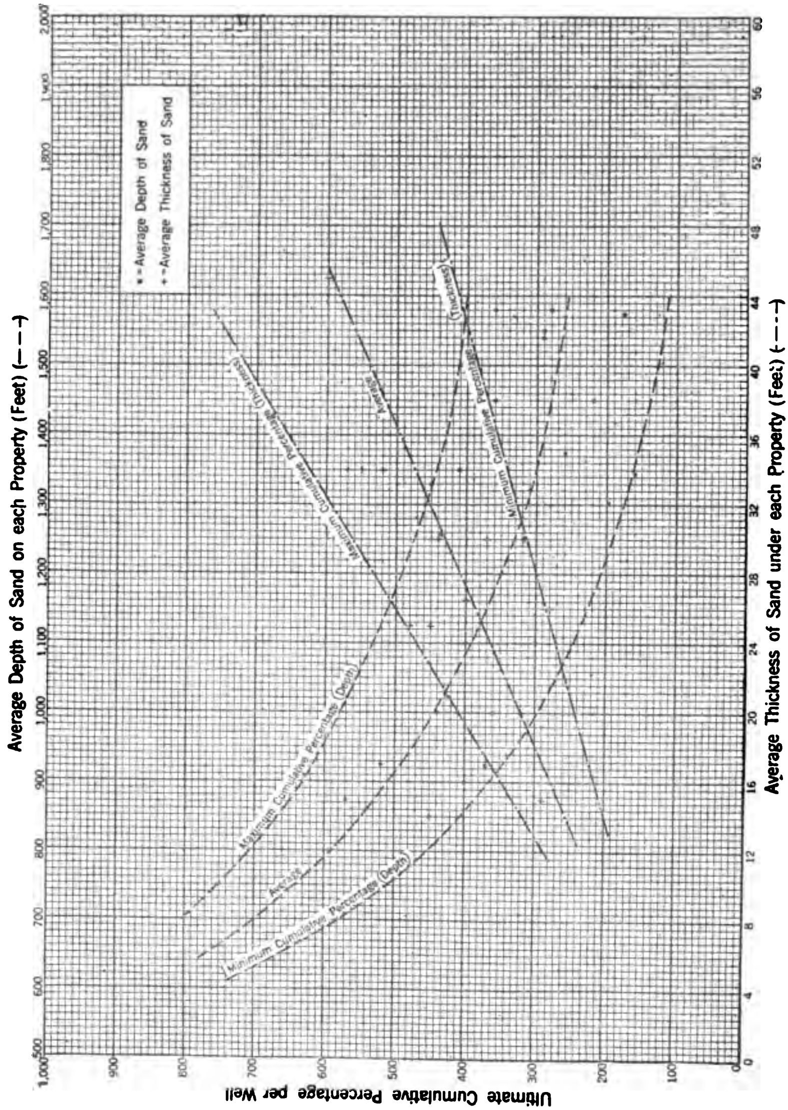


FIGURE 66.—Relation of average thickness and depth of sand to the ultimate cumulative percentage of several properties in the Lawrence County field, Ill.

TABLE 8.—*Average total production per acre for typical areas in Illinois.*

Sand.	Depth.	Period.	Production per acre.
	Feet.	*Years.*	*Barrels.*
Casey	350	10	5,309.93
Do	350	10	2,919.37
Robinson	[a] 900	9	719.14
Bridgeport	800-1,150	9	[b] 8,390.49
Buchanan	1,150-1,350	10	[b] 36,233.98
Kirkwood	1,350-1,650	9	[b] 2,546.22
McCloskey	1,750-2,000	8	[b] 15,672.80

[a] Average thickness, 7 feet.
[b] Many farms in Lawrence County have produced from four last sands a total of 62,000 barrels per acre, and the field is not yet exhausted.

The following table showns the average production per well of the wells on 19 properties in Lawrence County. The production per acre could not be determined because of lack of data as to the drilled acreage on each property.

TABLE 9.—*Average total production per well* [a] *on 19 properties in Lawrence County, Ill.*

Property.	Location.		Number of years producing.	Average production per well.[a]
	Section.	Township.		
				Barrels.
1	8	Bridgeport	10	30,000
2	19	Petty	10	32,000
3	13	do	8	27,000
4	29	do	10	26,000
5	31	Bridgeport	10	20,000
6	5	Dennison	8	12,000
7	24	do	9	8,000
8	2	do	9	14,000
9	35	do	9	29,000
10	22	do	10	20,000
11	4	Lawrence	9	25,000
12	8	Bridgeport	11	24,000
13	2	2 N., 12 W	8	33,000
14	25	Petty	7	21,000
15	22	Dennison	9	18,000
16		Bridgeport	9	12,000
17	7	Petty	9	20,000
18	13	do	5	23,000
19	5	Bridgeport	10	34,000

[a] Statistics on number of acres drilled on each property could not be obtained. Average acres per well in this field range from 7 to 10, so that an idea of the approximate productivity can be had by dividing production per well by the average acreage per well.

DECLINE CURVES OF THE CARLYLE AND SANDOVAL FIELDS, ILL.

Figure 67 shows decline curves of the two small and rather unimportant fields that lie west of the principal productive area in Illinois. The upper curve shows the decline of a property in the Carlyle, Clinton County, oil field; on it five wells are producing, the depth of the oil sand is 1,800 feet, and the average production per well during the first year was 2.3 barrels daily. The lower curve represents the decline curve of a property with 10 wells in the Sandoval pool, Marion County. The depth of the producing sand is approximately 1,500 feet, and the average daily production per well the first year was 15.5 barrels. These curves may or may not be representative, but they represent graphically all the available information on the decline of these two unimportant fields.

THE LIMA-INDIANA FIELD.

GENERAL STATEMENT.

One of the oldest fields in this country is the Lima-Indiana field, which lies in northwestern Ohio and northeastern Indiana. The oil comes mainly from the porous Trenton limestone, of Ordovician age, which is 1,000 to 1,600 feet deep. As the field, though once a large producer, is now practically exhausted, little time was spent in collecting

data for use in this bulletin. However, information was gathered on the total production per acre of properties in different townships throughout the whole field, and these figures, because of the age of

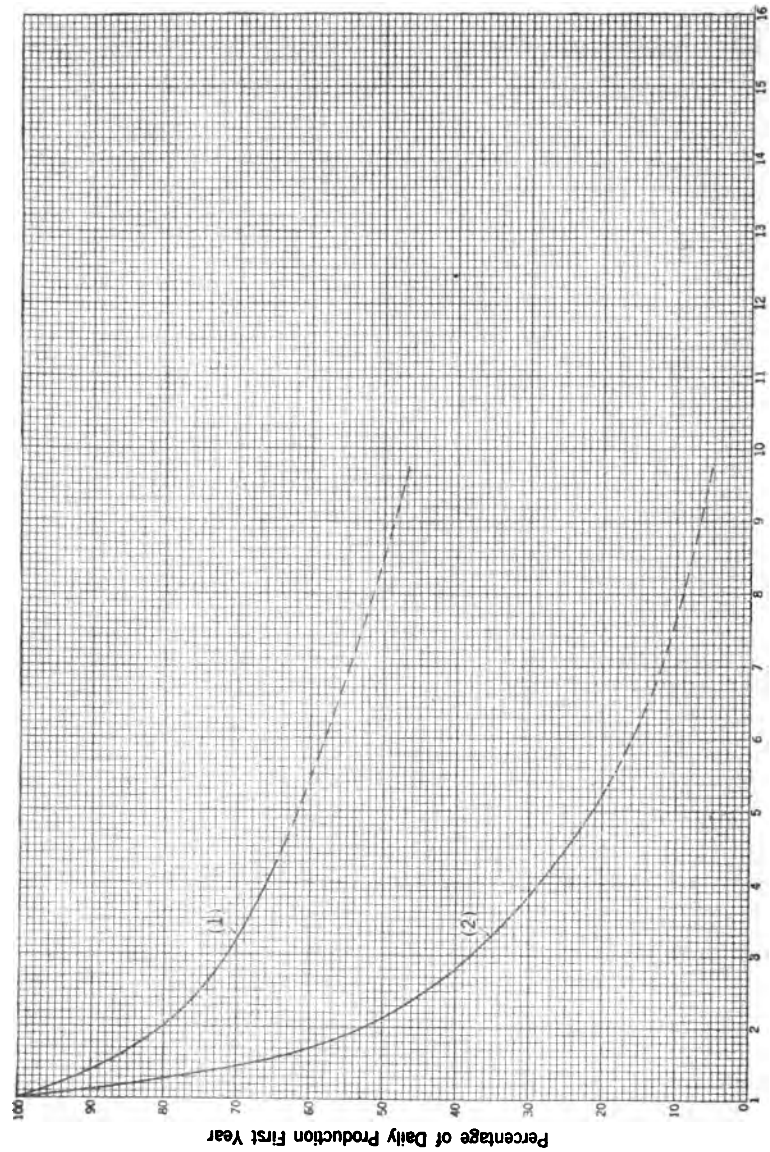


FIGURE 67.—Composite decline curves for the Carlyle and Sandoval oil fields, Ill. (1) Five wells in the Carlyle field; (2) 10 wells in the Sandoval field.

the field and the abandoning of many wells, may be taken as practically representing ultimate production.

AVERAGE AGE AND PRODUCTIVENESS OF PROPERTIES.

Figure 68 is a map showing the greater part of the Lima-Indiana field. On this map the approximate average age and total produc-

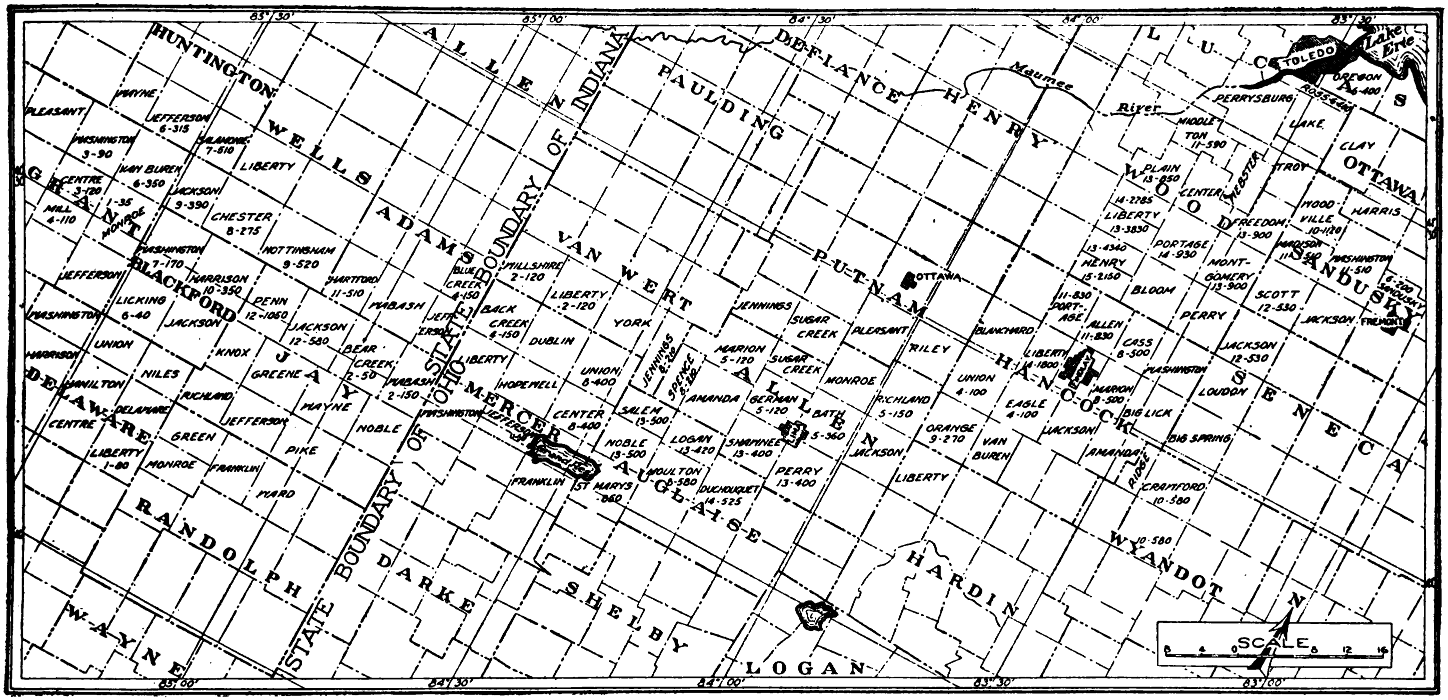


FIGURE 68.—Map of the Lima-Indiana field showing the average total production per acre of several properties in each township. The first figure in the lower right-hand corner of the township represents the approximate average age of production of the different properties in that township, and the second figure represents the total production per acre.

duction per acre on several properties in each township are shown, as indicated in the title to the figure.

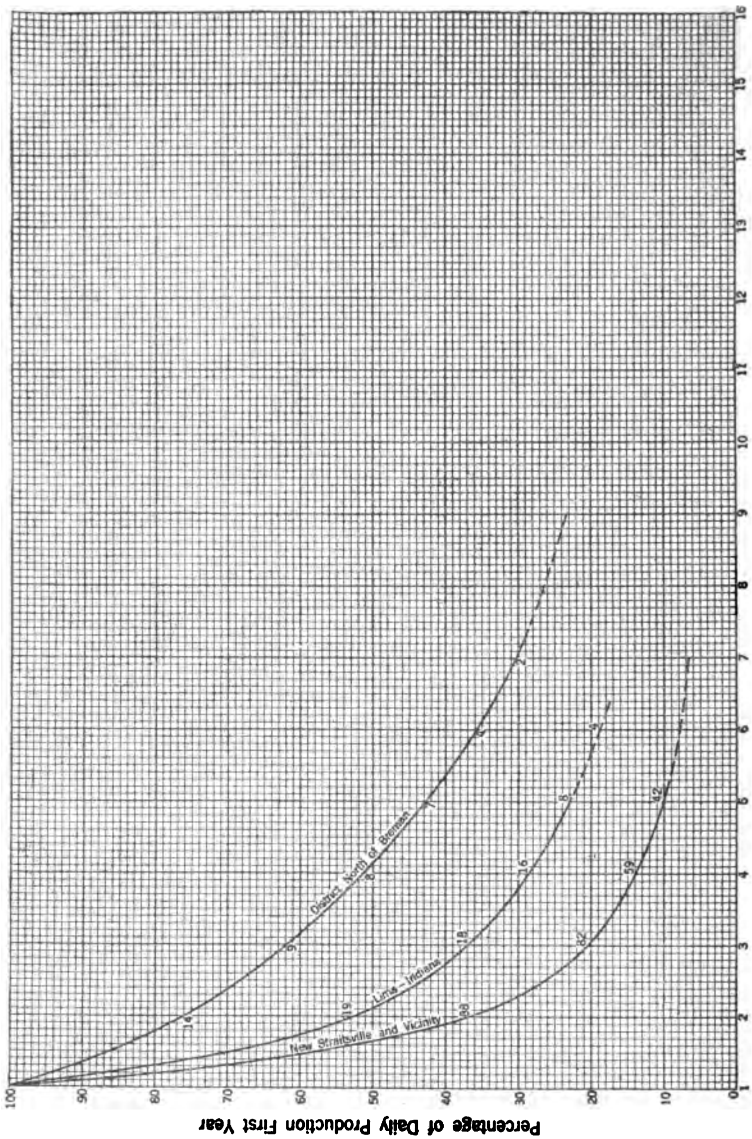


FIGURE 69.—Composite decline curves for two southeastern Ohio fields and of 19 properties in Lima-Indiana field.

COMPOSITE DECLINE CURVE OF 19 PROPERTIES.

Figure 69 shows the composite decline curve of 19 properties in the Lima-Indiana field. As these properties were drilled several years after the discovery of the field, and, in fact, after intensive drilling

had been concluded, the curve represents the average decline of properties of small initial output. The properties were selected at random from Hancock and Allen Counties, Ohio, and from Blackford County, Ind., but nearly all the records were taken from the Hancock County area. On these properties the average daily production the first year was only 1½ barrels per well.

THE SOUTHEASTERN OHIO FIELDS.

Some data were collected from two different localities in southeastern Ohio. Production records, depth of sand, thickness, and other information were obtained for 88 individual wells in the New Straitsville pool, and production records were collected for several isolated and disconnected areas north of Bremen, these areas being in Hopewell and Licking Townships, Licking County; Hopewell and Licking Townships, Muskingum County; Hopewell Township, Licking County; Jackson Township, Knox County; and Pike Township, Coshocton County. All of the production records were for individual wells.

THE NEW STRAITSVILLE POOL.

In this pool the production comes from the Clinton sand, which lies 3,000 to 3,200 feet deep. In the 88 wells of which records are available the thickness of sand is 17 to 38 feet, although the actual thickness that produces the oil is probably less than 10 feet. For these wells, the average daily production the first year was 22 barrels. The spacing of the wells is about eight acres per well; some "town-lot" drilling was done, but not enough to affect the data given.

APPRAISAL CURVE.

Figure 70 shows the appraisal curve constructed by using the records of the 88 wells in the New Straitsville pool and vicinity. It should be noted that the maximum and minimum limits established are rather narrow, because the factors controlling production are approximately identical over the whole area.

ESTIMATING CHART.

Figure 71 shows the estimating chart prepared from the appraisal curve. In order to avoid the use of a large sheet of logarithmic coordinate paper the chart had to be divided into two parts—one lying below the heavy diagonal line and the other above.

GENERALIZED DECLINE CURVE.

The generalized decline curves for this field are given in figure 72.

COMPOSITE DECLINE CURVE.

Figure 69, on page 178, shows the composite decline curve of the 88 wells in the New Straitsville pool and vicinity.

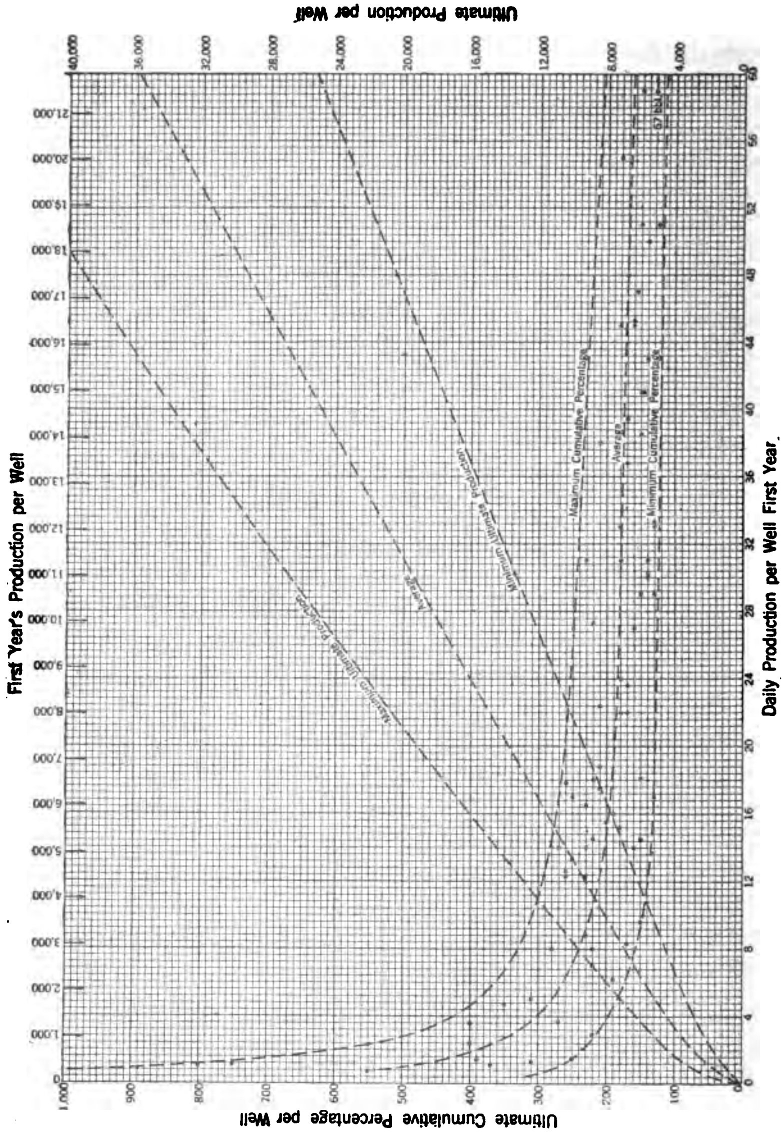


FIGURE 70.—Appraisal curve for the New Straitsville field, Ohio, and vicinity. Production figures are in barrels.

DISTRICT NORTH OF BREMAN.

In figure 69 is shown the composite curve for the properties in the isolated areas north of Breman. Although these wells are scattered they all produce from the Clinton sand, which lies 2,800 to 3,200

feet deep. This sand is 31 to 58 feet thick, averaging about 43 feet; the pay is 9 to 20 feet thick, averaging 10 to 12 feet. About 12 to

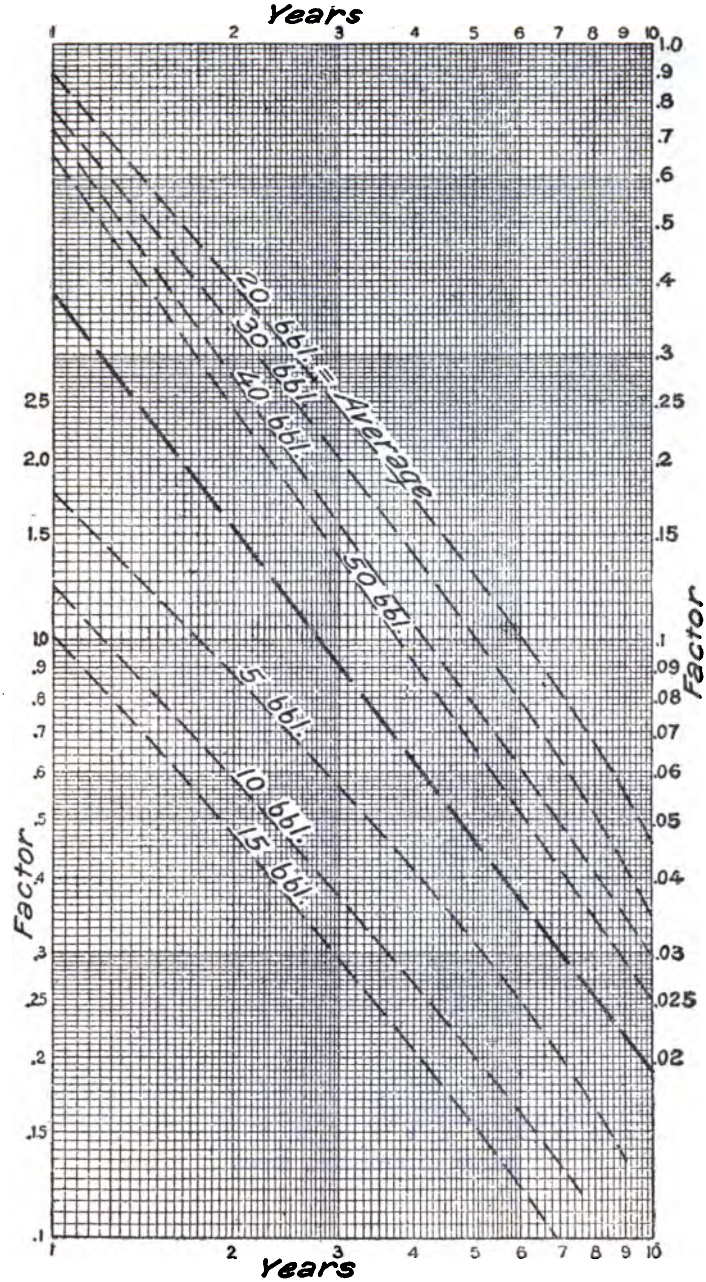


FIGURE 71.—Estimating chart for the New Straitsville field, Ohio, and vicinity.

18 acres were allotted each well, as compared with eight in the New Straitsville pool, and the average daily production per well the

first year was 12 barrels. Because of the larger acreage per well, the curve showing the average decline of these different properties differs

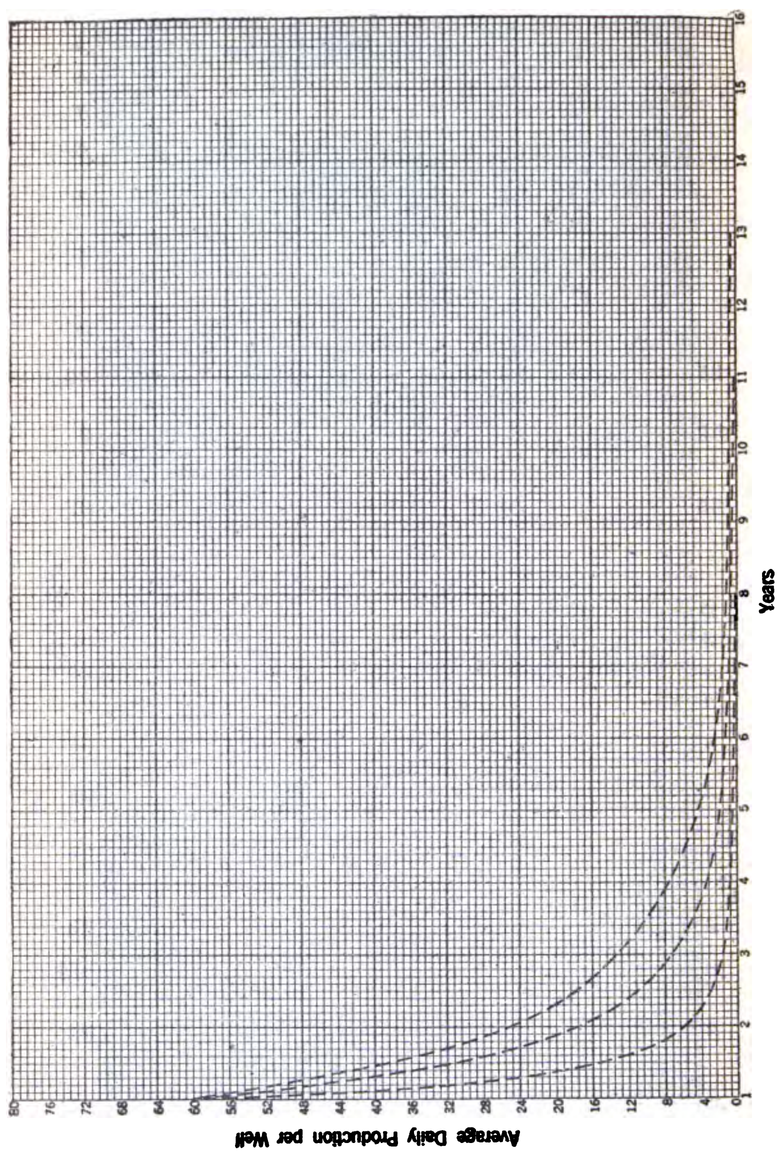


FIGURE 72.—Generalized decline curves for the New Straitsville field, Ohio, and vicinity. Production is in barrels.

widely from that of the average decline for New Straitsville and vicinity. The other factors that influence production in the two fields are approximately equivalent.

WEST VIRGINIA AND KENTUCKY.

GENERAL CONSIDERATIONS.

The Appalachian oil field extends southwest into West Virginia and Kentucky. In West Virginia the drilled areas cover many square miles, but the extent of the productive sands dwindles toward the southwest, so that the extension of the field in Kentucky has not been very productive. Not much information was collected in the States of West Virginia and Kentucky, the properties for which production records were gathered lying in Calhoun, Roane, Kanawha, Clay, and Lincoln Counties, W. Va., and in Lawrence and Morgan Counties, Ky. Few data were collected from the much-drilled area lying in West Virginia just across the Pennsylvania line. Depths of the producing sands differ greatly with the locality.

Fuller[a] gives some interesting statistics on the extent of the Appalachian oil and gas fields. The area of the Appalachian synclinorium is 70,000 square miles, and that of the oil field, including some potential oil land, is estimated at 2,504 square miles, or 3.6 per cent of the whole basin.

BLUE CREEK FIELD (W. VA.)

The Blue Creek field lies in Kanawha County, W. Va. The information obtained covers the Big Sandy, Wier Sand, and Elk districts, as well as the Rock Creek part of the Walton district.[b] Wells on these properties whose records were used in this study are drilled to the Squaw sand, 1,600 to 1,800 feet deep, and the Weir sand 1,700 to 2,100 feet deep. The Squaw sand, according to the records of wells, is 8 to 30 feet thick, whereas the average thickness of the Weir sand is about 13 feet. On properties producing from the Squaw sand the usual allotment is about 5 to 12 acres per well; and on those producing from the Weir sand, 8 to 12 acres per well. Some production is obtained from the Injun sand. Available records of production of wells to the Squaw sand for the properties of which records were available, is 15.2 barrels daily for the first year; for the Weir sand, 23 barrels; and for the one property producing from the Injun sand the average was 10 barrels.

Figure 73, which shows the composite decline curve of the wells on the Blue Creek field, indicates that the decline is very rapid, as the average well during the second year produces only 27 per cent of the amount it produced the first year. Curves are also shown for the decline of wells that produce from the Weir and the Squaw sands exclusively.

[a] Fuller, M. L., Appalachian oil field: Bull. Geol. Soc. Am., vol. 28, Sept. 30, 1917, p. 645.

[b] For the sake of uniformity the author has adopted the same classification of oil districts as that used by some of the oil companies.

THE LINCOLN COUNTY (W. VA.) AREA.

The information collected in Lincoln County covers entirely what is known by the companies as the Duvall district. In this district

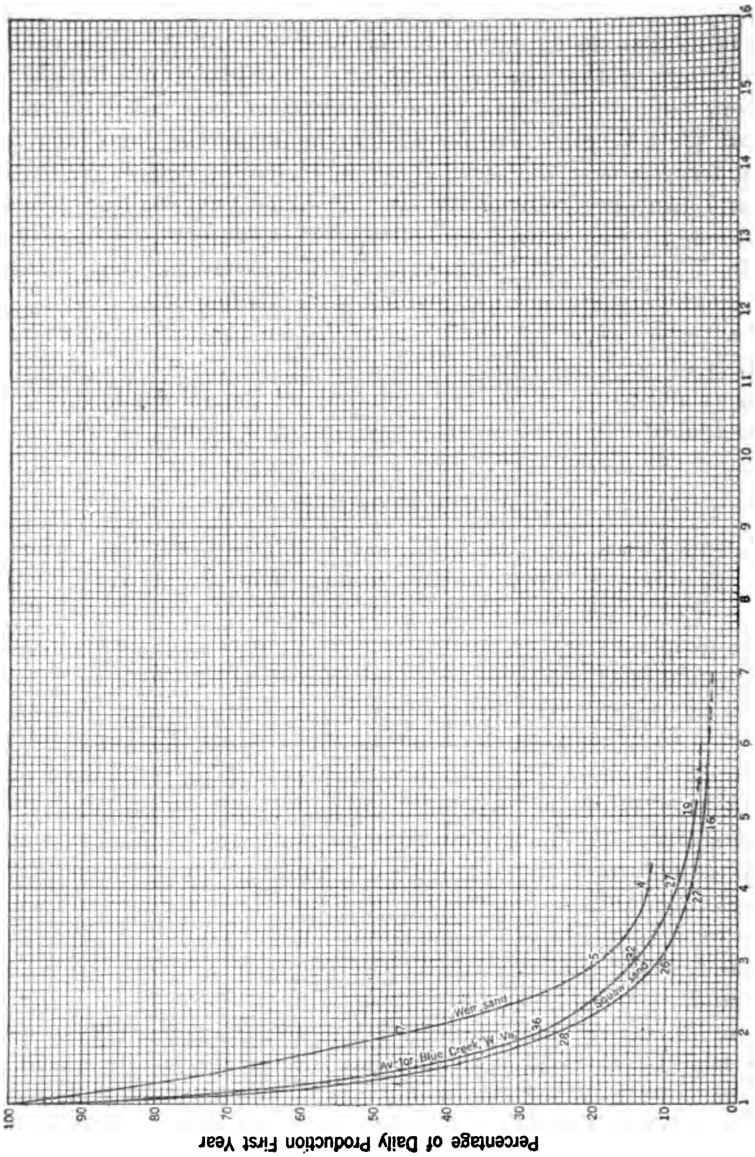


FIGURE 73.—Composite decline curves for wells producing from the Squaw and Weir sands in the Blue Creek field, W. Va., and for all the Blue Creek field.

the Berea sand is the productive formation. The sand has an average thickness of 20 to 22 feet under the 13 properties from which records were available, although the "pay" in many wells averages

about 9 feet. This sand lies 2,000 to 2,600 feet deep, and each well is allotted from 6 to 10 acres. On the 13 different properties the average daily production per well the first year was 17 barrels. The composite decline curve of 12 of these properties is shown on figure 74.

THE ROANE COUNTY (W. VA.) AREA.

Two curves on figure 74 represent the average decline of the Spencer and Rock Creek districts, respectively. These lie in Roane County, W. Va., the former including the Smithfield district and the Johnson Creek part of the Walton district, and the latter including the Harper district.

In the Spencer district the records of 21 properties were available. Wells on these properties produce from the Injun sand, and the average daily production per well during the first year was 22 barrels. The average thickness of the sand is 30 to 50 feet, although the pay is probably not as thick. Under the different properties the depth of the sand ranges from 1,800 to 2,100 feet, and the properties are drilled so that there are 7 to 10 acres for each well. The composite curve shown on figure 74 indicates that the average property in this district declines slowly for the first two or three years, for during the second year the output of the average well is about 69 per cent of its output for the first year. In the Rock Creek district the records of 10 properties were studied. All these properties produced entirely from the Injun sand, which ranges from 29 to 46 feet in thickness, and lies 1,800 to 2,100 feet deep. From 9 to 10 acres are allotted each well, and the average daily production the first year for all the wells on the 10 properties was 8 barrels. The curve showing the decline of seven of these properties is shown in figure 74.

CLAY COUNTY, W. VA.

Records of only two properties in Clay County were available. On these properties the wells produce from the Injun sand, the thickness of which in three wells on one property averages 24 feet, and in nine wells on the other property averages 32 feet. The depth of the sand is about 2,000 feet, and 10 acres are allotted each well. Not enough information was available to construct a composite decline curve, but the records of the two properties studied show that the decline for these properties, at any rate, is very slow, for during the second, third, fourth, and fifth years, the average percentage of the first year's production is successively 95, 94, 88, and 79.

LAWRENCE COUNTY, KY.

Five properties in Lawrence County were studied. The oil comes from the Berea sand, which is 40 to 65 feet thick, although the pay

sand is presumably not more than 10 feet thick, and the depth of the sand under the properties studied ranges from 1,650 to 1,800 feet. From 8 to 10 acres contribute to each well. The average daily

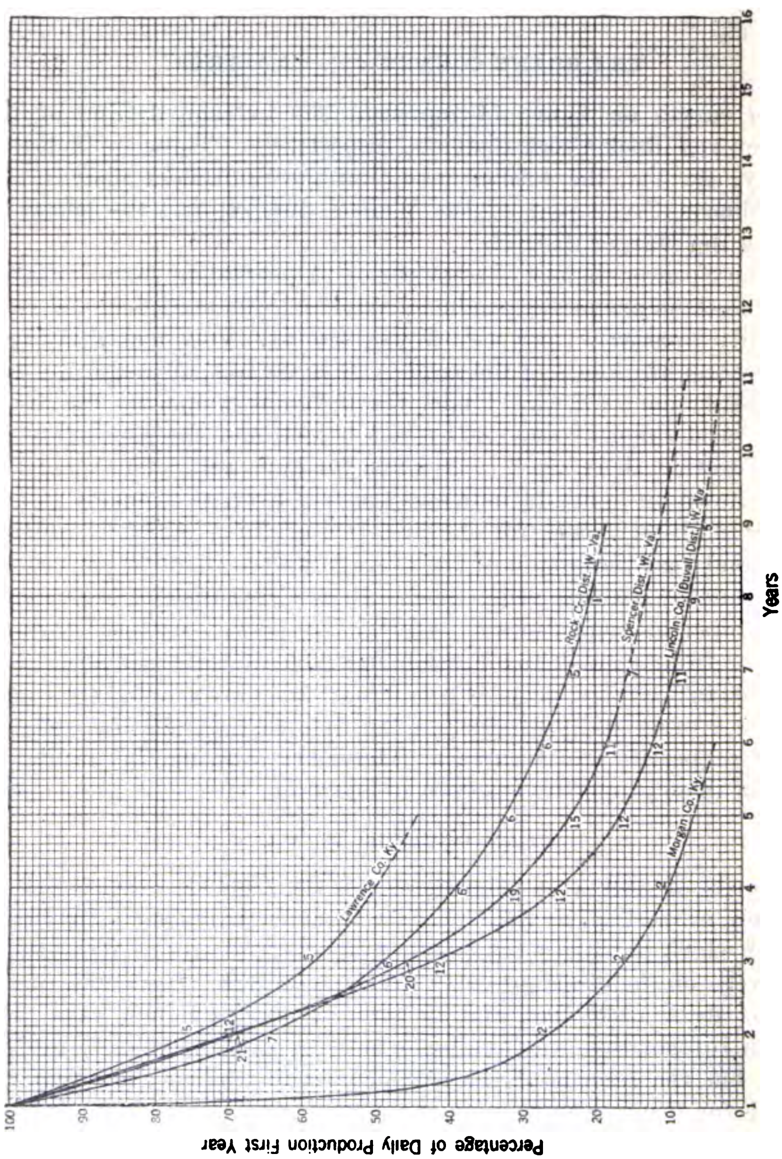


FIGURE 74.—Composite decline curves for the Rock Creek, Spencer, and Duvall (Lincoln County) districts, W. Va., and for Lawrence and Morgan Counties, Ky.

production per well the first year on five properties was only 3 barrels. The composite decline curve of these properties is shown in figure 74.

MORGAN COUNTY, KY.

Records of only two properties in Morgan County were available for study. The composite decline curve constructed is shown in figure 74. Most of the production comes from the Clinton sand, which ranges in thickness from 8 to 15 feet, and in depth from 1,800 to 2,000 feet. Each well drains oil from about eight acres, and the average daily production per well during the first year is 10 barrels.

The decline of these two properties should be compared with that of the New Straitsville field, Ohio (fig. 69, p. 178). In that field the oil comes from the Clinton sand, the spacing of the wells—eight acres each—is the same, but the initial yearly production and the depth of the sand are different. In the Morgan County field the decline is more rapid, probably because the Clinton sand is less productive than in the New Straitsville field.

DATA ON TOTAL PRODUCTION.

Data relating to the production of oil on a number of properties in West Virginia are given in the table following. The data comprise the total production per acre, the depth and thickness of sand, and the name of the chief producing sand.

TABLE 10.—*Total production per acre of several properties in different parts of West Virginia.*

Property.	District.	Years producing.	Average thickness of sand.	Approximate depth.	Principal sand producing.	Average production per acre.
Blue Creek field.			*Feet.*	*Feet.*		*Barrels.*
1	Big Sandy	5	18	1,600	Squaw	1,300
2	do	5	27	1,900	do	2,300
3	Weir Sand	5	30	2,100	Weir	300
4	do	3		1,600-2,100	do	4,100
5	Elk	5	13	1,800	do	2,000
6	do	6	13	1,700-1,800	Squaw	1 300
7	do	5	19	1,800	do	3,600
8	do	6	17	1,600	do	3,400
9	do	5	17	2,000	do	1,000
10	do	6	13		do	2,100
11	do	5	13	1,900	do	600
12	do	5	13		do	2,100
13	do	6		1,800	do	1,400
14	do	5	13	1,700	do	2,600
15	do	5			do	2,200
16	do	5	17		do	800
17	Big Sandy	5	8	1,900	Squaw and Weir	5,800
Lincoln County.						
1	Dewall	9	22	2,000	Berea	2,400
2	do	9	22	2,200-2,500	do	2,800
3	do	9	21	2,200	do	7,000
4	do	9	21	2,400-2,500	do	2,700
5	do	8	22		do	1,900
6	do	8	20	2,200-2,400	do	1,300
7	do	8	22	2,400	do	3,600
8	do	8	21		do	1,900

TABLE 10.—*Total production per acre of several properties in different parts of West Virginia*—Continued.

Property.	District.	Years producing.	Average thickness of sand.	Approximate depth.	Principal sand producing.	Average production per acre.
Roane County.			*Feet.*	*Feet.*		*Barrels.*
1	Rock Creek	8	39	2,000	Big Injin	1,400
2	do	8	39	2,000	do	2,500
3	do	7	42	1,900	do	2,100
4	do	10	43	2,000-2,200	do	1,900
5	do	10	43	2,000-2,100	Berea	1,800
6	Spencer	8	35	2,000	Big Injin	1,400
7	do	8	38	1,800	do	2,200
8	do	7	13	1,900	do	1,000
9	do	7	50	2,000	do	2,200
10	do	6	47		do	2,100
11	Smithfield	7	50	2,000	do	2,600
12	do	6	39	2,000	do	1,200
13	do	6	50		do	1,900
14	do	6	36		do	1,700
15	do	5	39		do	3,000
16	do	5	31		do	8,700
17	do	5	32		do	6,200

PENNSYLVANIA.

GENERAL STATEMENT.

The Pennsylvania fields were not studied in as great detail as the other fields of the United States for these reasons: (1) A great variety of conditions affects production; (2) the occurrence of oil and gas vary widely; (3) the age of many of the wells renders the collection of data extremely difficult; and (4) the fields lack importance as possible contributors of much more oil than they now contribute annually to the production of the United States. Some of the properties in Pennsylvania are more than 50 years old; fields have been discovered, pumped to exhaustion, and abandoned; even the location of many of the wells is not known. The information obtained by the author is not only meager, but is scattered widely over the productive part of the State.

AVERAGE DECLINE CURVE.

Figure 75 shows the average decline of the wells on 13 properties in the Oil City field, Venango County. In that field production, which never was large, is now slight, and the first year's production of the wells for which records were available was only 1.2 barrels daily. Most of the wells on these properties are pumped not oftener than once a week, leases with wells averaging one-tenth of a barrel a day being common, and 18 wells on one of the leases used in determining the average decline during 1916 produced only 0.07 barrel daily per well. In this district the spacing of the wells is about five acres per well. The initial production the first 24 hours of wells drilled at the present time is very small.

Pipe-line runs of one of the transportation companies that takes oil each month from about 32,000 wells in Pennsylvania show that

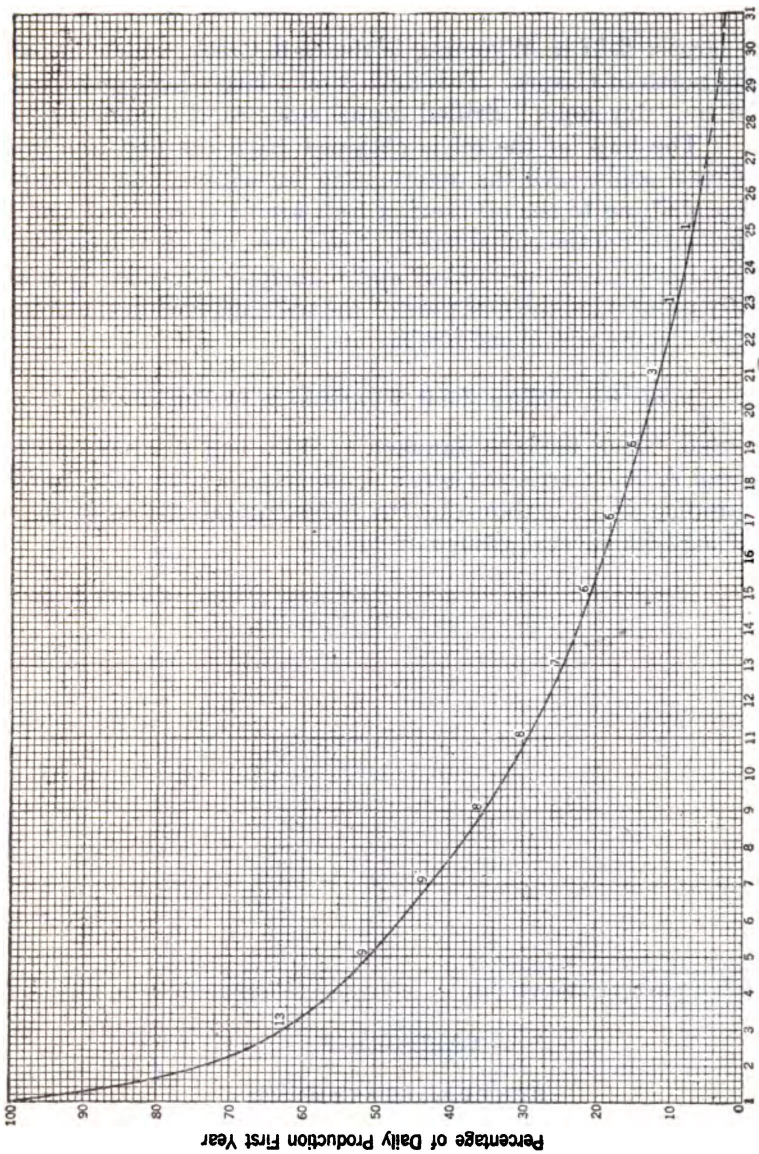


FIGURE 75.—Composite decline curve for the wells from 13 properties in the Oil City district, Venango County, Pa.

the average decline per well during 1916 was about 9 per cent. One company in the Oil City district allows the average well a decline each year of about 10 per cent of the preceding year's output, whereas

another company operating many hundred wells of small output states that the decline per well is about 6 per cent a year.

WYOMING.

The largest field in Wyoming is the Salt Creek, which lies about 45 miles north of Casper. This field is on a large dome and has been limited by "dry holes" drilled on all sides of the dome to "edge water." The bulk of the oil is obtained from the first and second Wall Creek sands. All the outcropping formations and those penetrated in drilling to the oil-bearing beds are of Cretaceous age.

Figure 76 gives the composite decline curve, which is based on the individual production records of approximately 50 wells. The average daily production the first year of the wells utilized in the preparation of this curve was about 100 barrels.

DATA ON TOTAL AND ULTIMATE PRODUCTION.

The Salt Creek field, to January 1, 1918, had produced between 15,000 and 20,000 barrels per acre. In some places the field is exceedingly productive, as is shown by the following tabulation of the output per acre for several groups of wells:

TABLE 11.—*Total production per acre of different groups of wells in the Salt Creek oil field, Wyoming.*

Group of wells.	Location.			Years producing.	Number of wells.	Production per acre.
	Section.	Township, N.	Range, W.			
						Barrels.
1	36	40	79	6	7	63,500
2	25	40	79	6	4	33,000
3	25	40	79	4	a 1	23,000
4	36	40	79	6	b 9	5,000
5	26	40	79	4	a 1	13,000
6	26	40	79	40	a 1	5,000
7	25	40	79	6	5	20,000
8	25	40	79	4	a 1	9,000
9	27	40	79	5	3	4,000

a Each well assumed to drain 10 acres. b Majority of wells drilled during last two years.

CALIFORNIA.

GENERAL STATEMENT.

Although the California oil fields were not investigated as thoroughly as the available information warrants, such data as were collected are given because of its possible use to others. Only the San Joaquin Valley fields were studied. Some of the composite decline curves given were prepared by the appraisal committee of the Independent Oil Producer's Agency during 1914 and 1915. As

the time the author had for collecting data was short, not enough information was obtained for preparing similar curves for any of the

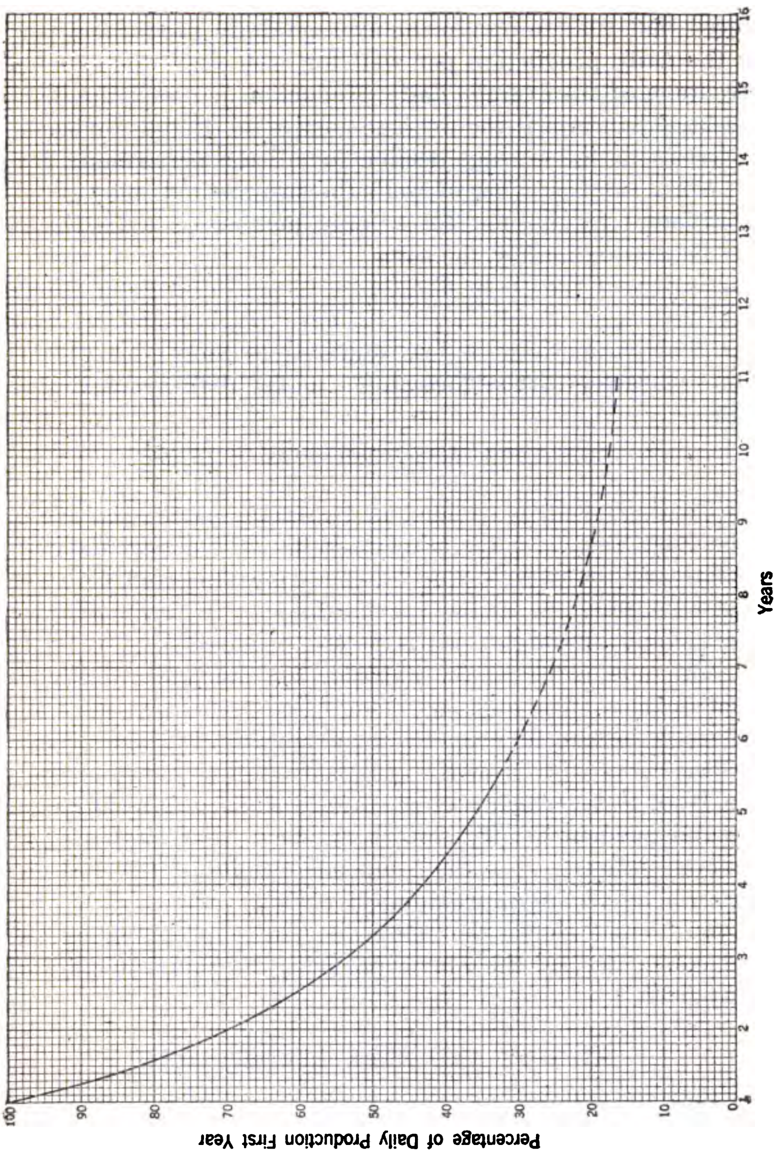


FIGURE 76.—Composite decline curves for the Salt Creek field, Wyo.

fields excepting the Midway and the Coalinga, where the curves prepared check fairly well with the older curves of the appraisal committee that recently were published by Requa.[a] That committee

[a] Requa, M. L., Method of valuing oil lands: Am. Inst. Min. Eng. Bull. 134, February, 1918, pp. 409–428.

in preparing composite decline curves used a method different from that of the author, the sum of the production of all the wells for each year being divided by the sum of the number of days each well produced that year to obtain the average daily production per well. Then the daily production per well for each year was expressed as a percentage of the average daily production per well the first year. The writer determined the average composite decline for each well, and afterwards the average decline for all the percentages for each year. For a small number of wells the two methods may give somewhat different results, but for a large number of wells the results should be approximately the same.

Practically all the oil in California is produced from formations of Tertiary age. Producing wells have reached the oil sands at depths that range from a few hundred to more than 4,000 feet, and the character of the formations makes drilling expensive and difficult.

COALINGA AND MARICOPA FIELDS.

The Coalinga field is divided in two main parts—the West Side and the East Side. On the West Side the oil has accumulated on a monocline and the outcropping oil sands are cemented with asphalt. On the East Side the oil has accumulated on the crest of the Coalinga anticline. Enough records of the production of wells on the East Side were collected to construct the composite decline curve for that district. The numbers along these curves indicate the number of wells, instead of properties, entering the average. Figure 77 shows this curve as well as the composite decline curve of the wells on the West Side, which was prepared by the appraisal committee of the Independent Oil Producer's Agency. The similarity of the two curves indicates that the composite results of the factors governing production are approximately equal.

Figure 77 also shows the composite curve, prepared by the appraisal committee, of the Maricopa field, the southern part of the Midway field.

MIDWAY AND KERN RIVER FIELD.

The Midway field may be divided into two parts or districts. In one of these the oil has accumulated along a monocline and on an anticline, so that the depth of the sands has a rather wide range; in the other, which lies in the Buena Vista Hills, the oil accumulated on a large well-defined anticline. The principal part of the Buena Vista Hills has been set aside by the Federal Government as Naval Petroleum Reserve No. 2.

COMPOSITE DECLINE CURVES FOR ALL WELLS.

As the two districts differ in depth of oil sands, quality of oil, and other conditions a composite decline curve was prepared for each. These curves are shown in figure 78.

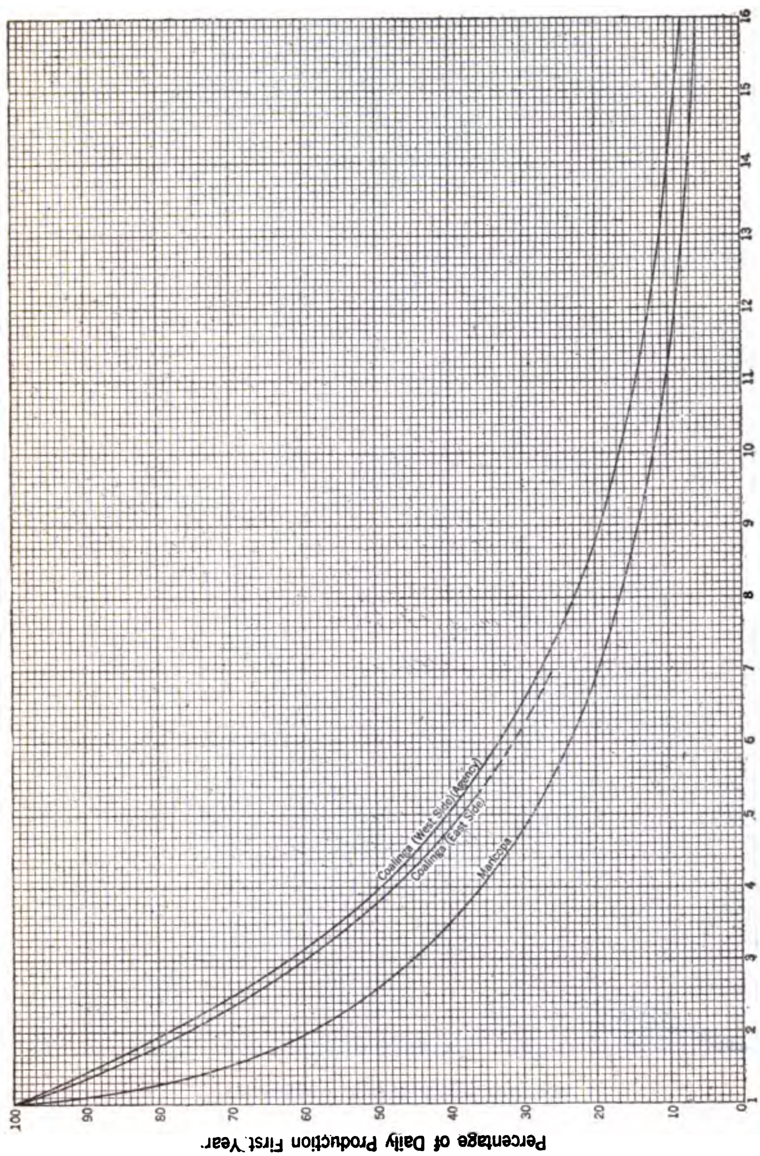


FIGURE 77.—Composite decline curves for the East Side and West Side Coalinga fields and the Maricopa field, Cal.

For the wells used in preparing the curve for the Midway field, excluding Naval Petroleum Reserve No. 2, the average daily production

per well the first year was 115 barrels. The curve showing the average decline for the whole Midway field, including Naval Petroleum Reserve No. 2, was compiled from the records of more than 150 wells.

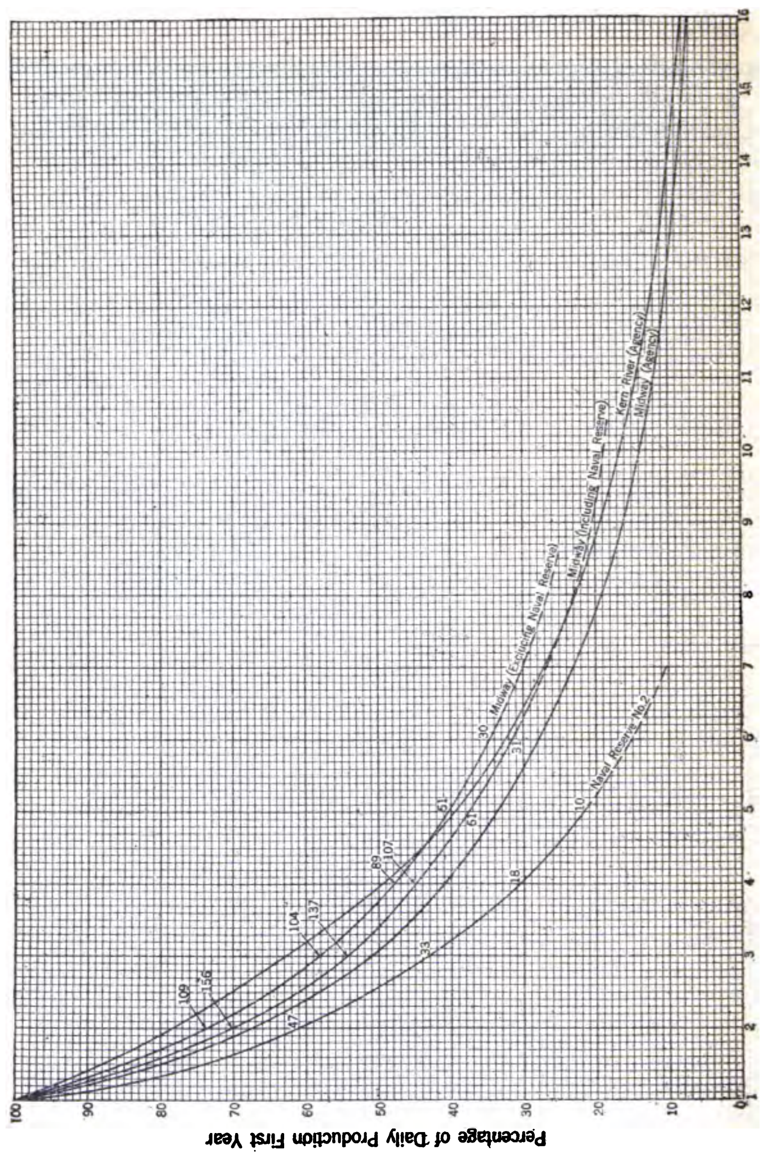


FIGURE 78.—Composite decline curves for parts of the Midway field, for all the Midway and for the Kern River field, Cal.

For these wells the average daily production per well the first year was 189 barrels. The curve prepared by the appraisal committee (fig. 78) shows a more rapid rate of decline than the curve prepared

by the author. This difference may be a result of the different methods used in preparing the curves, or it may be due to the fact that the average well as determined by the appraisal committee was larger than that determined by the author.

The curve that shows the average decline of Naval Petroleum Reserve No. 2 was prepared from the individual production records of about 50 wells. As the figure shows, these wells decline much more rapidly than the wells for the Midway field with Naval Petroleum Reserve No. 2 excluded. The curve prepared by the appraisal committee for the Kern River field is also shown in figure 78.

In order to compare the rate at which these different groups of wells decline the table following has been prepared:

Production during second year, decline during second year, and ultimate cumulative percentage of wells in the Midway field.

Group.	First year's daily production.	Ratio of second year's production to first.	Ultimate cumulative percentage.
	Barrels.	*Per cent.*	*Per cent.*
Midway field, excluding Naval Petroleum Reserve No. 2	115	74	575
Midway field, including Naval Petroleum Reserve No. 2	189	70	520
Naval Petroleum Reserve No. 2	461	61	300
Midway field (I. O. P. Agency figures)	....	67.5	500

COMPOSITE DECLINE CURVES FOR WELLS OF DIFFERENT SIZES.

Conditions affecting production in the Midway field are so variable that much more information would have been necessary to prepare appraisal curves than was available; consequently another method was adopted to determine the approximate decline of wells of different sizes. The wells were divided into classes in accordance with the average daily production the first year. In Naval Petroleum Reserve No. 2, these classes were as follows: Wells that made daily the first year from zero to 100 barrels, from 101 to 200 barrels, from 201 to 300 barrels, and from 301 to 400 barrels. The average daily production per well the first year for each class was, in order, 66, 154, 262, and 334 barrels. Figure 79 gives the composite decline curve of the wells for each class. By use of these curves estimates of future production in this district can be made with greater accuracy when the first year's production of a well is known. Although the curves show the average decline of wells of different sizes within certain limits, they should not be used to estimate future production if more exact curves can be made by collecting additional records, for in the construction of some of these curves, the records of only a few wells were available.

Similar calculations were made for the Midway field with the wells in Naval Petroleum Reserve No. 2 excluded. The record of

only one well producing between 400 and 500 barrels was available. In addition, the decline of a well making 624 barrels daily the first year and one making 1,400 barrels daily the first year are given.

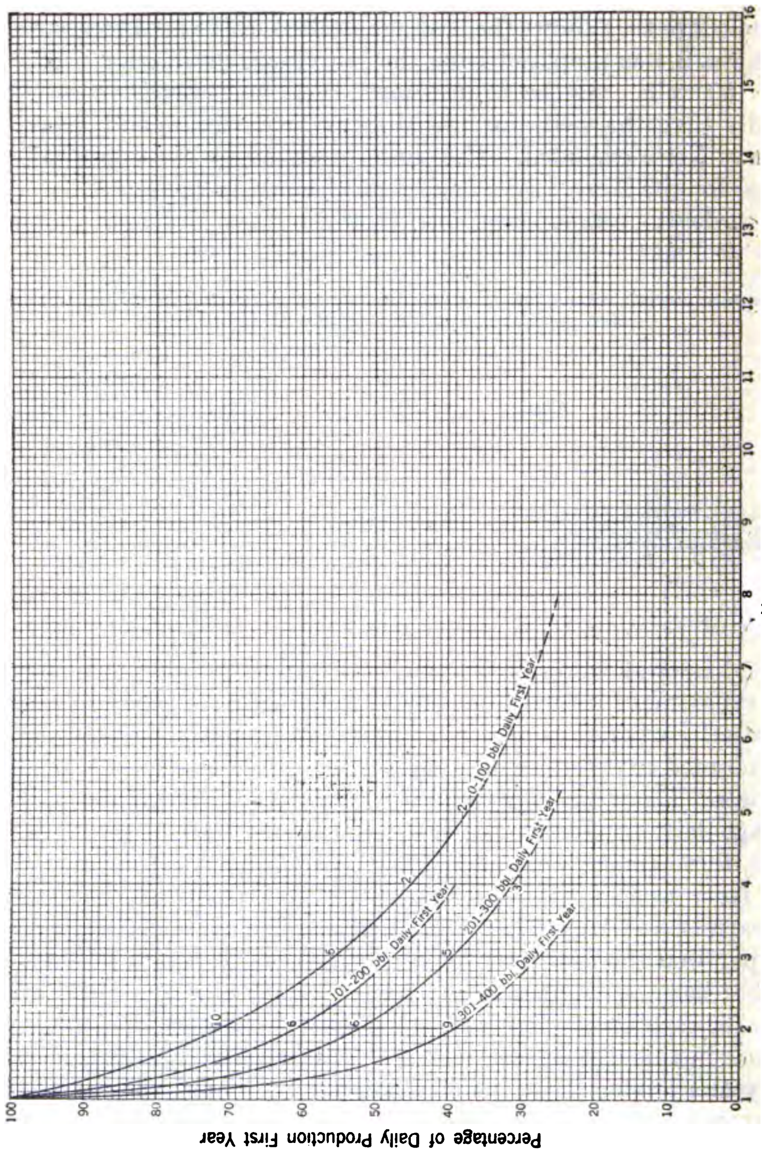


FIGURE 79.—Composite decline curves for groups of wells of different output in Naval Petroleum Reserve No. 2.

The difference in the rate of decline of these wells clearly shows the fallacy of using the composite decline curve. It should never be used if other more complete curves are available. These decline curves are given in figure 80.

For wells that made between zero and 100 barrels or less daily the first year the average daily production per well the first year was 49

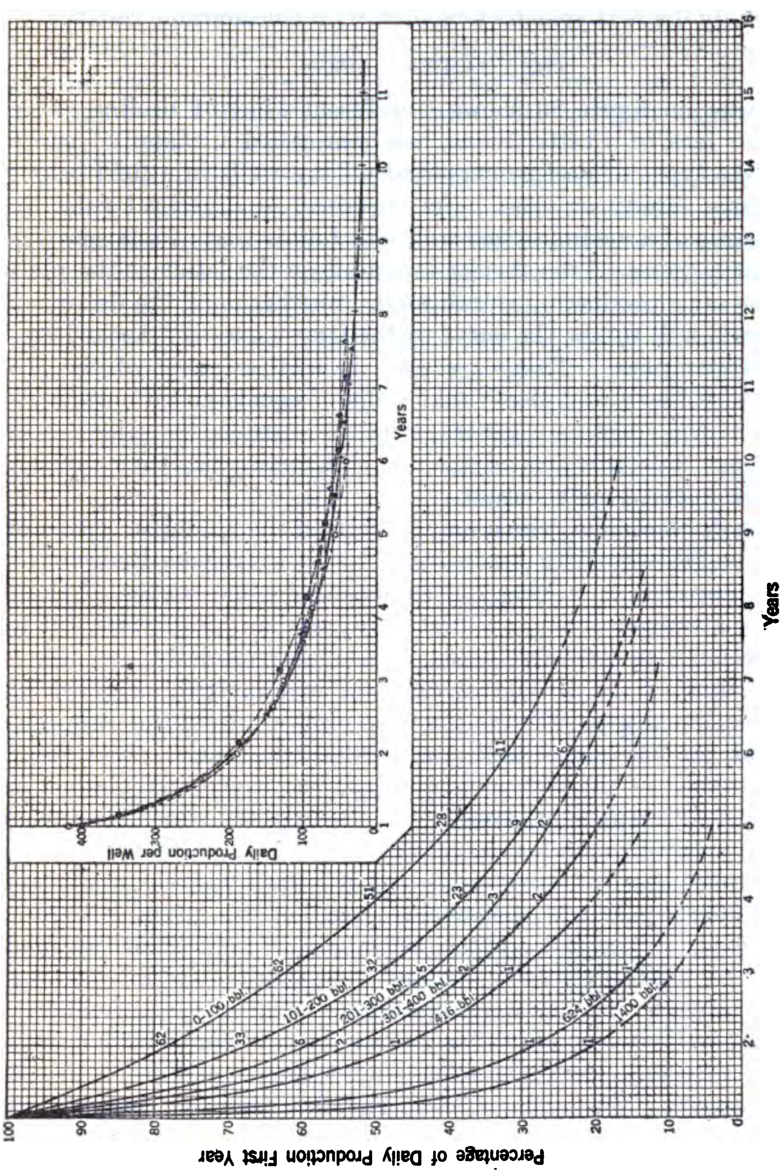


FIGURE 80.—Composite decline curves for groups of wells of different output in the Midway field, exclusive of Naval Petroleum Reserve No. 2. Inset shows "family" curve prepared from the other curves, which proves that wells of equal output in this field will generally furnish the same future production regardless of the ages of the wells.

barrels; for wells that made 101 to 200 barrels it was 148 barrels; and for wells that made between 201 and 300 barrels it was 237 barrels. Furthermore, a curve of two wells averaging 350 barrels

daily the first year is given. Because of the large number of individual well records utilized, the two uppermost curves, those showing the decline of wells that made 100 barrels or less and 101 to 200 barrels daily the first year may be used with considerable reliance.

THE "FAMILY" CURVE.

The inset on figure 80 shows a different kind of decline curve, which, for lack of a better name, has been called a "family" curve, because the types of decline curves of all the wells in a field belong to the same family or class. For instance, as a general rule, the decline curve of a medium-sized well will follow that of a larger well if the initial point of the former is placed on the latter at the place where the same production is indicated. Furthermore, the decline of a small well will follow the curve of the larger ones if "hooked on" at the proper place. This, of course, is further proof of the law advanced by Lewis and Beal[a] that wells of equal settled output, regardless of their age, as a general rule will furnish the same future production. For this reason the lives of wells will vary directly with their initial yearly output.

The heavy black line, which may be termed the "family" curve of wells in the Midway field (exclusive of Naval Petroleum Reserve No. 2), was prepared by taking the composite decline curves of those wells that averaged during the first year less than 100 barrels, 101 to 200 barrels, 201 to 300 barrels, 350, and 416 barrels daily.

The decline of the 416-barrel well was first plotted, as shown by the dashed line drawn through the open circles. Next the composite decline of the 350-barrel well was plotted, the initial point being the intersection of the 350-barrel line and the curve first plotted, as shown by the line passing through the filled circles, which represents the daily production each year of such a well. The segment of the curve between the first open circle at 416 barrels and the first filled circle at 350 barrels was considered a part of the "family" curve of that field. Then the composite decline of wells that averaged from 201 to 300 barrels daily the first year was plotted in a similar manner, as shown by the open triangles. Similarly the composite declines of wells that made 101 to 201 barrels and zero to 100 barrels daily the first year were plotted, as indicated by the filled triangles and the crosses. Thus the segments of the "family" curve were determined from point to point, the second segment being shown between the filled circles and the open triangles, the third between the open triangles and the closed triangles, and the fourth between the first closed triangle and the first cross. From that point on—a little past the sixth year—the curve follows the composite decline curve determined by the closed triangles and the crosses.

[a] Lewis, J. O., and Beal, C. H., Some new methods for estimating the future production of oil wells: Am. Inst. Min. Eng. Bull. 134, February, 1918.

One of the most striking characteristics of these curves is the narrow variation between the composite decline curves of wells of different output. Thus the well that made 416 barrels daily the first year produced approximately 43 barrels daily during the sixth year. During the same sixth year a new well was brought in that averaged approximately 50 barrels daily during its first year. Both wells, although they differ in age by 5 years, will produce approximately the same amounts in the future.

There can be no question as to the utility of such a curve or its superiority to a composite decline curve and possibly, if enough data are available, to an appraisal curve as the yearly production and thus the decline of a well of almost any output can be determined by reading directly. For example, if a well during the first year produced 260 barrels daily, measuring to the right a distance of one time unit gives the probable production for the second year, or 150 barrels. Similarly the production for the third, fourth, fifth, sixth, and seventh years is successively 100, 75, 55, 45, and 35 barrels. Furthermore, the future production can easily be determined by adding the future yearly production, and the life of the well may be determined by counting the years to the point of the well's exhaustion.

In addition limits of the decline of wells following this curve may be determined by plotting on the "family" curve, the actual decline of individual wells.

The "family" curve has many advantages over any other type of curve, but because of lack of time the one shown was the only one prepared. The generalized decline curves, derived from the appraisal curves for each field and shown throughout the report are based on the same principle and should be noted.

In using this or similar curves, the reader should note that the production of a well must be one year old before its future can be determined. As an aid, general curves could be prepared for determining the approximate relation of the initial production the first 24 hours, or at the end of 30 days, to the average daily production the first year. With such general curves, the probable daily production the first year can be approximated when the well is a day or a month old.

DATA ON TOTAL AND ULTIMATE PRODUCTION OF CALIFORNIA OIL FIELDS.

Accurate statistics have been kept by different companies of the total production each year in the different California fields. Statistics showing the amount produced to December 31, 1917, the proved

acreage, and the total production per acre are given in the following tabulation taken from the Standard Oil Bulletin.[a] As regards the figures for area, the Bulletin says:

In determining the figures the boundary lines of the proven area are drawn 200 or 300 feet outside of the proven field. In case of outlying single wells the field is credited with about 15 acres.

The figures therefore represent the actual proven area, and give no consideration to territory that is generally regarded as proven but is not fully drilled. For instance, large areas of undrilled territory in the Buena Vista Hills, although regarded as proven, are not included in the following tabulation.

The proven acreage as shown is, therefore, low as compared with figures made by others. Other estimates have run as high as 110,000 acres, or 171.88 square miles.

TABLE 12.—*Proven acreage, total production to Dec. 31, 1917, and the total production per acre for the different California oil fields.*

Field.	Proven acreage.	Total production to Dec. 31, 1917.	Total production per acre to Dec. 31, 1917.
		Barrels.	*Barrels.*
Kern River	7,730	198,645,210	25,698
McKittrick	1,635	52,114,761	31,874
Midway-Sunset	40,204	291,822,154	7,259
Lost Hills-Belridge	4,476	28,426,055	6,351
Coalinga	14,771	196,872,731	13,328
Lompoc and Santa Maria	7,710	80,913,461	10,495
Ventura County and Newhall	4,514	19,924,745	4,414
Los Angeles and Salt Lake	2,700	52,902,331	19,593
Whittier-Fullerton	4,575	115,584,105	25,264
Summerland	[1] 230	2,180,334	9,480
Miscellaneous	[1] 200	964,727	4,824
	88,745	1,040,350,614	11,723

[1] Estimated.

The McKittrick field, the most productive in the State, has yielded approximately 32,000 barrels an acre. For the whole State the average yield per acre is very high as compared with averages for other States, such as Oklahoma.

An accurate inventory of the present undrilled locations in California has been taken by the State oil and gas supervisor, R. P. McLaughlin, and submitted to the petroleum committee of the California Council of Defense.[b] These locations were classified according to their probable productiveness the first year, and the writer has used the statistics in estimating the probable future production of the undrilled areas in the California fields.

On the assumption that the average ultimate cumulative percentage of the California wells is approximately 500, the undrilled wells in the State, provided they are drilled during the next few years,

[a] Proven territory in California: Standard Oil Bulletin, April, 1918, p. 11.

[b] Report of Committee on Petroleum, California Council of Defense, 1917, pp. 131, 140, 141.

will ultimately produce about 1,300,000,000 barrels of oil. The probable future production of the producing wells has been estimated at approximately 1,000,000,000 barrels, so that the estimated total future production for California is about 2,300,000,000 barrels. The present proved territory, according to Table 12, is 88,745 acres, but it includes only land on which wells have been drilled. The undrilled areas comprise about 72,000 acres, making the total productive acreage 160,745 acres. As the past production has been a little more than 1,000,000,000 barrels, and the estimated total future production is 2,300,000,000 barrels, the ultimate production per acre (3,300,000,000 ÷ 160,745) is about 20,500 barrels.

THE KUROKAWA OIL FIELD, JAPAN.

Some information has been collected on individual wells belonging to the Nippon Oil Co., in the Kurokawa oil field, Province of Ugo, Japan. Figure 13 (p. 54) shows the average daily production the first week of wells drilled during succeeding months. The composite decline of several scores of wells the first three years has been determined to be, successively, 100, 49, and 29 per cent. As shown by figure 13, the ultimate cumulative percentage is approximately 300. The oil sand is reported as loose and fine, 2 to 5 feet thick, and 1,100 to 1,400 feet below the surface. The initial production of the wells (daily average the first week) ranges from 2 to more than 5,000 barrels.

COMPARISON OF THE DECLINE AND APPRAISAL CURVES OF SEVERAL FIELDS.

Interesting and fruitful subjects for future investigation are the study of the factors governing output in different fields, the way in which each factor influences the average rate at which the oil is obtained, and effect of each factor on the ultimate cumulative percentage or ultimate production. By determining these factors, the probable future of other fields and properties, where the same factors have approximately equal value, can be much more easily estimated.

For instance, let it be assumed that the individual and composite effect of all the important factors influencing the rate of production in the Bartlesville field (Okla.), are known. The thickness of the oil sand does not vary much, the wells are spaced a certain distance, and, as the depth is fairly uniform, the rock pressure is about the same. By an analysis of these data, one can determine how almost any important factor affects the ultimate production per acre and the rate at which the oil is obtained. Now if the value of each production factor in a field can be determined, the estimating of the possibilities of properties in other fields where one or more of the

tant production factors are similar, will be greatly facilitated. The problem is to determine the individual effects of the different factors.

To determine how various field conditions affect the decline curve and the ultimate cumulative percentages, tables have been prepared that recapitulate the conditions influencing production in the different fields studied. Table 13 gives data on the principal fields for which enough information was available to justify inclusion here. Column 2 shows the average daily production the first year of the wells used in constructing the composite curve; column 3, gives the second year's percentage of the first year's average daily production, which is an excellent indication of the probable productiveness of the field as a whole; and column 4 shows the approximate ultimate cumulative percentage of the average well in each field.

TABLE 13.—*Comparison of the ultimate and the second year's percentages of average wells in different fields.*

Field.	Average daily production first year.	Second year's percentage of first year's production.	Approximate ultimate cumulative percentage.
1	2	3	4
Oklahoma:	*Barrels.*	*Per cent.*	*Per cent.*
Bartlesville	17	49	310
Osage (eastern)	35	63	330
Bird Creek-Flat Rock	30	60	300
Nowata	19	50	270
Glenn pool	45	51	240
Okmulgee-Morris	38	52	320
Hamilton Switch	56	55	320
Muskogee pool	24	44	210
Ponca City	32	61	320
Cushing:			
Layton sand	34	32	235
Wheeler sand	53	23	175
Bartlesville sand	208	30	220
Healdton	67	62	420
Kansas (shallow)	4	75	750
North Texas: Electra	75	51	330
North Louisiana:			
Caddo	66	54	290
Red River	475	23	....
De Soto	190	35	....
Crichton	85	28	....
Gulf Coast:			
Humble pool (cap rock)	47	51	....
Humble pool (deep sand)	289	38	....
Sour Lake pool	84	39	....
Spindletop pool	92	45	....
Saratoga pool	23	53	....
Illinois:			
Crawford County	11	52	280
Clark County	3	65	350
Lawrence County	100	61	370
Southeastern Ohio: New Straitsville pool	22	37	210
West Virginia:			
Blue Creek	17	27	170
Duvall district (Lincoln County)	17	69	280
Rock Creek	8	65	470
Spencer	22	70	350
Wyoming: Salt Creek	100	69	460
California:			
Coalinga (East Side)	180	76	480
Coalinga (West Side)	....	79	574
Kern River	....	78	550
Midway	189	70	520
Maricopa	....	59	445
Japan: Kurokawa	89	49	300

UNIFORMITY OF THE SECOND YEAR PERCENTAGE AND THE ULTIMATE CUMULATIVE PERCENTAGE FOR OKLAHOMA FIELDS.

It is interesting to note the uniformity of the second year's percentage in the individual pools of a large area where the conditions that affect production are approximately the same. This uniformity is well shown by the fields of Oklahoma, if the Cushing field be excluded, because of extraordinary conditions and the Muskogee pool because of few data. For the remaining Oklahoma fields the lowest percentage for the second year is 49 per cent in the Bartlesville field, whereas the highest percentage, 63 per cent, is the Osage Indian Reservation, a few miles west. The probable cause for this difference is that the area allotted each well in the Bartlesville field is only about one-half of that allotted in the Osage Indian Reservation. Inasmuch as the rate of decline of oil wells is influenced by the spacing of the wells such a difference in spacing ought to exert a marked influence on the decline of the average wells.

In the eight Oklahoma fields under consideration the average second year's percentage is 55 per cent; the maximum limit 63 per cent; the minimum limit 49 per cent; and the maximum and minimum variation above and below the average are respectively 15 and 11 per cent. Hence the following general rule can be laid down: *Average* wells in Oklahoma fields producing under ordinary conditions will average during the second year 55 per cent of their first year's yield, and the chances are that the second year's yield will not exceed this amount more than 15 per cent nor fall below it more than 11 per cent. In other words, it is fairly safe to assume that a well which averaged 33 barrels daily the first year, which is the average for all pools, will average between 50 and 60 per cent of that much the second year.

For these normal fields in Oklahoma the ultimate percentages show the same uniformity, ranging from 240 to 330. In other words, the average well in these fields will produce ultimately not less than about 2.4 times and not more than about 3.3 times its first year's production. Other similarities of fields in other areas may be noted, especially where the conditions that affect production do not vary widely.

In the Cushing field three different sands have yielded the bulk of the oil. Production from all these sands declined much more rapidly than from sands in the other Oklahoma fields. The principal cause of this rapid decline was the great waste of gas. Furthermore, the wells were unsystematically cased and water was allowed to flood some of the sands.

The percentages given in columns 3 and 4 of Table 13 vary because of the range of the conditions affecting production in the different fields. The magnitude of the effect of each factor can not always

be determined, and the rate at which the output of a well declines is a resultant of the composite influence of all the factors that in any manner govern the production of oil. However, the influence of one factor may predominate. For instance, the dominating factor in causing the decline of wells in the Bartlesville field to differ from that of wells in the Osage Indian Reservation seems to be the difference in the spacing of the wells. Unquestionably, however, the greater depth of the wells in the Osage Indian Reservation has influenced the rate of decline of the wells there considerably, because of the increased gas pressure and the consequently higher initial output. Other factors evidently must have an opposite effect, thus counterbalancing the effect of the difference in depth.

GENERAL TENDENCIES OF FACTORS CONTROLLING OUTPUT.

The questions naturally arise: What are the general tendencies of the output of wells producing under certain conditions? Under what conditions do wells tend toward large and small ultimate productions? Answers may be found in Table 14, suggested to the author by J. O. Lewis, of the Bureau of Mines, which gives the general tendency of the ultimate cumulative percentage and the ultimate production of wells producing under certain conditions.

TABLE 14.—*General tendencies of wells producing under specified conditions.*[a]

Condition.	Rate of decline.	General tendency of ultimate cumulative percentage.	General tendency of ultimate production.
Deep wells	Rapid	Small	Large.
Shallow wells	Slow	Large	Small.
High rock pressure	Rapid	Small	Large.
Low rock pressure	Slow	Large	Small.
Large initial production	Rapid	Small	Large.
Small initial production	Slow	Large	Small.
Close spacing	Rapid	Small	Small.[b]
Wide spacing	Slow	Large	Large.[c]
Thick sand	do	do	Large.
Thin sand	Rapid	Small	Small.
Large pore space	do	do	Large.
Small pore space	Slow	Large	Small.
High-gravity oil	Rapid	Small	Large.
Low-gravity oil	Slow	Large	Small.
With water trouble	Rapid	Small	Do.[d]
No water trouble	Slow	Large	Large.
Properly operated	do	do	Do.
Poorly operated	Rapid	Small	Small.

[a] In this table the influence of any one factor is given on the assumption that all other factors are without influence.
[b] Small per well but large per acre.
[c] Large per well but small per acre.
[d] In some cases, when water floods in, the ultimate production will be greatly increased.

TENDENCIES IN THE NEW STRAITSVILLE POOL, OHIO.

An excellent example of the way in which these tendencies work can be had by comparing the second year's percentage and the ultimate cumulative percentage of wells in the New Straitsville pool,

Ohio, as shown by Table 13 (p. 202), with the conditions prevailing there. In that pool the second year's production is 37 per cent of the first year, and the ultimate cumulative percentage is 210; the average daily production of wells the first year is low; the pay sand is probably not more than 10 feet thick and the walls are approximately 3,000 feet deep and rather closely spaced. According to Table 14, the depth of these wells, the high rock pressure, the thin sand and the closeness of spacing all favor rapid decline and small ultimate cumulative percentages, and the small initial production is the only factor favoring a large ultimate cumulative percentage. Unquestionably, the composite effect of the four factors tending toward a small ultimate cumulative percentage is much stronger than the tendency of the one factor favoring a large ultimate cumulative percentage. For other fields the effects of similar factors and the tendency toward high or low ultimate cumulative percentages can be determined in much the same way.

VARIATIONS IN ESTIMATES OF ULTIMATE PRODUCTION BASED ON APPRAISAL CURVES.

Variations above and below the average in estimates of ultimate production made from the appraisal curves of the different fields are summarized in the table following, which shows the maximum and minimum error that may be expected in estimating the ultimate output.

TABLE 15.—*Probable error above and below the average of the maximum and minimum estimates of ultimate production.*

Field.	Daily production per well.[a]	Maximum ultimate production.	Average ultimate production.	Minimum ultimate production.	Possible error above average.	Possible error below average.
	Barrels.	*Barrels.*	*Barrels.*	*Barrels.*	*Per cent.*	*Per cent.*
Osage Nation, Okla.	150	140,000	103,000	78,000	36	24
Bartlesville field, Okla.	75	65,000	50,000	35,500	30	29
Bird Creek-Flat Rock, Okla.	65	71,000	55,000	39,500	29	28
Nowata field, Okla.	60	36,000	30,600	25,500	18	17
Glenn Pool, Okla.	100	106,500	81,000	54,500	31	33
Caddo field, La.	200	199,000	146,000	98,000	36	33
Crawford and Clark Counties, Ill.	24	20,300	16,000	11,700	23	27
Lawrence County, Ill.	50	54,600	40,000	25,600	37	36
New Straitsville, Ohio.	30	25.700	19,400	13,300	32	31

[a] Selected by determining the mean average daily production as shown in the respective appraisal curves.

In selecting the output of the well for which the ultimate production was to be estimated, the mean between the two extremes of daily production shown on the lower side of the appraisal curve was selected in order to have all estimates on the same basis. For instance, in the Osage Nation, Okla., the average daily production the first year ranged up to 300 barrels. Therefore, the ultimate

production of a 150-barrel well was determined and the variation above and below the average estimate was computed. Except for the Nowata field (Okla.), the percentage of variation of the maximum and minimum limits above and below the average is fairly uniform, the maximum limits ranging from 23 to 37 per cent above the average and the minimum limits from 24 to 36 per cent below the average. The table thus serves as an index of the range of error that may be expected in appraisal curves for the different fields.

SELECTED BIBLIOGRAPHY.

THE DECLINE AND ULTIMATE PRODUCTION OF OIL PROPERTIES.

GOVERNMENT AND STATE REPORTS—ARTICLES IN TECHNICAL JOURNALS AND PROCEEDINGS OF SOCIETIES.

ARNOLD, RALPH, The petroleum resources of the United States: Economic Geology, vol. 10, December, 1915, pp. 695–712.

BUCKLEY, E. R., Building and ornamental stones in Wisconsin: Wisconsin Geol. and Nat. Hist. Survey, Bull. 4, econ. ser. No. 2, 1898, p. 402.

DAY, DAVID T., The petroleum resources of the United States, a chapter in the conservation of mineral resources: U. S. Geol. Survey, Bull. 394, 1909, pp. 30–50.

HAGER, DORSEY, Geological factors in oil production: Min. and Sci. Press, vol. 109, December 9, 1911, pp. 738–741.

HUNTLEY, L. G., Possible causes of the decline of oil wells and suggested methods of prolonging yield: Tech. Paper 51, U. S. Bureau of Mines, 1913, 32 pp.

LEWIS, J. O., and BEAL, C. H., Some new methods for estimating future production of oil properties: Am. Inst. Min. Eng., Bull. 134, February, 1918, pp. 477–504.

LOMBARDI, M. E., The cost of maintaining production in the California oil fields: Trans. Am. Inst. Min. Eng., 1916, pp. 218–224.

MCLAUGHLIN, R. P., Petroleum industry of California: California State Mining Bureau, Bull. 69, 1914, 519 pp.

PACK, R. W., The estimation of petroleum reserves: Trans. Am. Inst. Min. Eng., vol. 57, 1918, pp. 968–981.

THELEN, MAX, BLACKWELDEN, ELIOT, and FOLSOM, D. M., Report of the committee on petroleum: California State Council of Defense, July 7, 1917, 191 pp.

WASHBURNE, C. W., The estimation of oil reserves: Am. Inst. Min. Eng., Bull. 98, February, 1915, pp. 469–471.

BOOKS.

BRINTON, W. C., Graphic methods for presenting facts. 1914. 371 pp.

HAGER, DORSEY, Practical oil geology. 1916. 187 pp.

JOHNSON, ROSWELL H., and HUNTLEY, J. G., Principles of oil and gas production. 1916. 371 pp.

PEDDLE, JOHN B., The construction of graphical charts. 1910. 109 pp.

THOMPSON, A. BEEBY, Oil-field development. 1916. 684 pp.

THE VALUATION AND TAXATION OF OIL PROPERTIES.

GOVERNMENT REPORTS—ARTICLES IN TECHNICAL JOURNALS AND PROCEEDINGS OF SOCIETIES.

ASHLEY, G. H., The valuation of public coal lands: U. S. Geol. Survey Bull. 424, 1910, 75 pp.

BYLLESBY, H. M., Responsibilities of engineers in making appraisals: Trans. Am. Inst. Elect. Eng., vol. 32, pt. 2, 1911, pp. 1251–1265.

CABELL, R. E., Basis for estimating special excise tax on corporations: Oil Age, vol. 5, March 1, 1912, p. 2.

FORSTNER, W., The valuation of oil lands: Min. and Sci. Press, vol. 103, 1911. p. 578.

HAGER, DORSEY, Valuation of oil properties: Eng. and Min. Jour., vol. 101, May 27, 1916, pp. 930–932.

HAYS, V. A., Depreciation of natural gas properties: Progressive Age, vol. 30, pp. 787–788.

HENRY, P. W., Depreciation as applied to oil properties: Trans. Am. Inst. Min. Eng., vol. 51. 1916, pp. 560–570.

JOHNSON, ROSWELL, Methods of prospecting, development, and appraisement in the Mid-Continent field: Oil Investor's Jour., vol. 8, February 20, 1910, pp. 70–73.

KNIGHT, ALFRED, Discussion of depreciation: Journal of Accountancy, vol. 5, 1907, p. 189.

REQUA, M. L., Methods of valuing oil lands: Am. Inst. Min. Eng., Bull. 134, February, 1918, pp. 409–428.

BOOKS.

FLOY, HENRY, Valuation of public utility properties. 1912. 390 pp.

HOOVER, H. C., Principles of mining. 1901. 109 pp.

HOSKOLD, H. D., Engineer's valuing assistant. 1905, 185 pp.

HUMPHREYS, A. C., Business features of engineering practice. 1905. 187 pp.

JOHNSON, R. H., and HUNTLEY, L. G., Principles of oil and gas production. 1916. 371 pp.

LEAKE, P. D., Depreciation of wasting assets. 1917. 233 pp.

MACLEOD, H. D., Elements of economics. 1881–1886. 2 vols.

O'DONAHUE, T. A., The valuation of mineral property. 1910. 158 pp.

SCHOOLING, W., Inwood's tables for the purchasing of estates, etc. 1913. pp.

THOMPSON, A. BEEBY, Oil-field development. 1916. 684 pp.

WYER, S. S., Regulation, valuation, and depreciation of public utilities. 1913. 313 pp.

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